

ENDEAVOUR
VOL. 7
1948
G K V
HARDWAR

R
505
L84E
V.(VI)



anar Foundation Chennai

main: Gurukul Kangri Coll



यह पुस्तक वितरित न की जाय
NOT TO BE ISSUED

सन्दर्भ ग्रन्थ
REFERENCE BOOK

077819

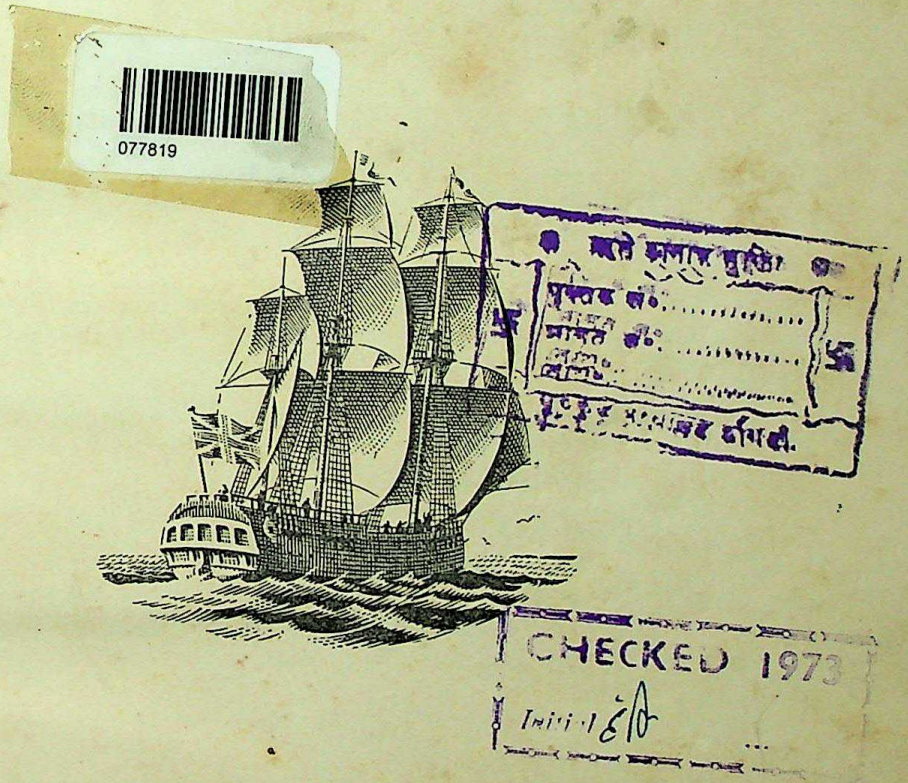
VII · 1948

आर्य समाज ११८४-११८५

A

ENDEAVOUR

A quarterly review designed to record the progress
of the sciences in the service of mankind



VOLUME VII · 1948

पुस्तक नमूना संख्या ११८४-११८५

AUTHOR INDEX

Digitized by Arya Samaj Foundation Chennai and eGangotri

	Page
ALDINGTON, J. N. The high-intensity flash-discharge tube	21
J. N. ALDINGTON, B.Sc., Ph.D., A.R.I.C., F.Inst.P., is Assistant Works Manager for Messrs. Siemens Electric Lamps and Supplies Ltd. and is responsible for technical development and control. He has twice been awarded the Leon Gaster Memorial Premium for theses on fluorescent light sources.	
BACSICH, P. (See WYBURN, G. M.)	165
P. BACSICH, M.D., D.Sc., F.R.S.E., has been senior lecturer in Histology and Embryology in Glasgow University since 1937. He has published work on histological methods, neurology, embryology, and endocrinological aspects of reproductive physiology.	
CHAIN, E. Chemical properties and structure of the penicillins, Parts I and II ..	83, 153
E. CHAIN, D.Phil., is University Demonstrator in Chemical Pathology in the Sir William Dunn School of Pathology, Oxford. With Sir Howard Florey he initiated the research which led to the practical development of penicillin and he played a leading part in its chemical investigation. This work gained for him a Nobel Prize for Physiology and Medicine in 1945. He was elected a Commander of the Legion of Honour in 1947.	
CLARKE, A. C. Rocket exploration	70
A. C. CLARKE was an officer in the R.A.F. during the war and was in charge of the first Ground Controlled Approach Radar during development trials in the United Kingdom with Radiation Laboratory scientists. He is chairman of the British Interplanetary Society.	
DUVEEN, DENIS I. Some symbols used by the alchemists	116
D. I. DUVEEN, F.R.I.C., is Joint Managing Director of Ashe Laboratories Ltd. He has published several papers on historical and bibliographical matters relating to the history of chemistry.	
EDITORIAL Science in Italy ..	1
Macromolecules ..	41
Symbolism in science ..	81
Scientific information ..	129
EMELÉUS, H. J. Fluorine chemistry ..	141
H. J. EMELÉUS, A.R.C.S., D.Sc., F.R.S., has been Professor of Inorganic Chemistry at Cambridge since 1946. He was previously at Princeton University and Imperial College.	
EVANS, D. S. Solar prominences	159
D. S. EVANS, Ph.D., F.Inst.P., is Second Assistant at the Radcliffe Observatory, Pretoria. He was previously at the University Observatory, Oxford. His chief scientific interest is in astrophysics. He is also keenly interested in popular scientific writing.	
GAUTHERET, R. J. Plant tissue culture	75
R. J. GAUTHERET, D.Sc., has been Professor of Plant Biology at the Sorbonne since 1942. His researches are chiefly concerned with plant tissue culture, a field in which he was one of the first to achieve success.	
HARTLEY, P. H. T. Animal camouflage	97
P. H. T. HARTLEY, B.Sc., is a member of the staff of the Department of Zoological Field Studies at Oxford.	
JOHNSON, B. K. The polarization microscope	57
B. K. JOHNSON, D.I.C., is lecturer in the Physics Department of Imperial College and is a Recognized Lecturer of the University of London.	
JONES, SIR HAROLD SPENCER (See SPENCER JONES, SIR HAROLD)	
KARRER, PAUL Carotenoid pigments	3
P. KARRER, Ph.D., Dr.Med.(h.c.), Dr.Pharmac.(h.c.), For.Mem.R.S., has been Director of the Chemical Institute of the University of Zürich since 1919. He is well known for his researches on vitamins, carotenoids and other plant products, amino-acids, carbohydrates, and organic arsenical compounds. He was awarded a Nobel Prize for Chemistry in 1937.	
LAPAGE, G. Parasitic animals and the world's food	27
G. LAPAGE, M.A., M.D., has been a parasitologist at Cambridge since 1930. He has written two books and many articles on this subject.	
MCKIE, DOUGLAS Boyle's law	148
D. MCKIE, Ph.D., D.Sc., is Reader in the History of Science in the University of London. He is one of the founders and editors of <i>Annals of Science</i>.	
MEES, C. E. K. Modern colour photography	131
C. E. K. MEES, D.Sc., F.R.S., joined the Eastman Kodak Company at Rochester, N.Y., in 1912. He became director of research and development for the company in 1918, and vice-president in charge of research in 1934. He has published nearly one hundred papers on the theory of photography.	
MEINESZ, F. A. VENING (See VENING MEINESZ, F. A.)	

NEWMAN, W. A. C.	British coinage and coinage alloys	15
W. A. C. NEWMAN, B.Sc., A.R.C.S., D.I.C., F.R.I.C., is Chemist and Assayer at the Royal Mint, with which he has been associated since 1912. He is a member of council of the Institution of Mining and Metallurgy and treasurer of the Institute of Metals.		
PARTINGTON, J. R.	John Dalton	54
J. R. PARTINGTON, M.B.E., D.Sc., has been Professor of Chemistry in the University of London (Queen Mary College) since 1919. He has a wide knowledge of the history of chemistry, to which subject he has extensively contributed.		
PAULING, LINUS	Antibodies and specific biological forces	43
LINUS PAULING, B.S., M.A., Ph.D., D.Sc., For.Mem.R.S., is Professor of Chemistry and chairman of the Division of Chemistry and Chemical Engineering at the Californian Institute of Technology. His chief interests are in crystal structure and in the application of quantum mechanics to problems of molecular structure. Since 1940 he has been interested also in immunochemistry. His chemical researches have brought him honours from universities and learned societies in both the United States and Great Britain.		
PIPPARD, A. J. S.	The masonry arch	122
A. J. S. PIPPAED, M.B.E., D.Sc., M.I.C.E., has been Professor of Civil Engineering in the University of London at Imperial College since 1933. He is a member of council of the Institution of Civil Engineers.		
RAWLINS, IAN	Scientific methods in the conservation of pictures	104
I. RAWLINS, M.A., M.Sc., F.R.S.E., F.Inst.P., was appointed first scientific adviser to the trustees of the National Gallery, London, in 1934. Since 1945 he has been Assistant Keeper. He has published numerous papers in <i>Technical Studies in the Field of the Fine Arts</i> and other journals.		
SPENCER JONES, SIR HAROLD	The Royal Observatory, Greenwich	9
SIR HAROLD SPENCER JONES, M.A., Sc.D., B.Sc., F.R.S., F.R.A.S., has held the position of Astronomer Royal since 1933. He is a past president of the Royal Astronomical Society and of the British Astronomical Association, and was vice-president of the International Astronomical Union from 1935 to 1938. He has recently been elected to membership of the <i>Accademia dei Lincei</i> .		
TAYLOR, CHARLES B.	The bacteriology of lakes	III
C. B. TAYLOR, B.S.A., Ph.D., D.Sc., F.R.I.C., was in 1938 appointed the first bacteriologist to the Freshwater Biological Association at Ambleside, England. During the war he worked with the staff of the Water Pollution Research Laboratory in problems relating to the newly established British flax industry.		
TORTONESE, ENRICO	Lazzaro Spallanzani: founder of experimental physiology	92
E. TORTONESE, D.Sc., has been assistant in the Museum and Institute of Zoology of the University of Turin since 1932. In 1937 he was also appointed Lecturer in Zoology. His chief interests are in problems of systematics, zoogeography, and ecology.		
VENING MEINESZ, F. A.	Gravity surveys in submarines	170
F. A. VENING MEINESZ, D.Sc., For.Mem.R.S., is Director-in-chief of the Royal Netherlands Meteorological and Geophysical Institute at De Bilt. He has made many gravity determinations during voyages in submarines of the Netherlands and United States Navies.		
WARDLAW, C. W.	Tropical fruits: their storage and transport	32
C. W. WARDLAW, Ph.D., D.Sc., F.R.S.E., has been Professor of Cryptogamic Botany in the University of Manchester since 1940. He was previously associated with the Imperial College of Tropical Agriculture, Trinidad, British West Indies, investigating problems relating to the transport and storage of tropical fruit.		
WARDLAW, WILLIAM	Structural inorganic chemistry	66
W. WARDLAW, D.Sc., F.R.I.C., has been Professor of Physical Chemistry in the University of London (Birkbeck College) since 1937. Since 1939 he has been an honorary secretary of The Chemical Society. He has published numerous papers on co-ordination compounds.		
WYBURN, G. M., and BACSICH, P.	The grafting of animal tissues	165
G. M. WYBURN, D.Sc., M.B., F.R.F.P.S.G., F.R.S.E., joined the staff of the Anatomy Department, Glasgow University, in 1930 and became senior lecturer in 1937. He has recently been appointed Regius Professor of Anatomy. His chief interests are in embryological problems and reproductive endocrinology.		

SUBJECT INDEX

ANTIBODIES and specific biological forces, LINUS PAULING	43
ARCH, The masonry, A. J. S. PIPPAED	122
BACTERIOLOGY of lakes, The, CHARLES B. TAYLOR	III
BOYLE'S Law, DOUGLAS MCKIE	148
CAMOUFLAGE, Animal, P. H. T. HARTLEY	97

		Page
	CAROTENOID pigments, <i>Digitized by A.P.S. Foundation Chennai and eGangotri</i>	3
	COINAGE and coinage alloys, British, W. A. C. NEWMAN	15
A	FLASH-DISCHARGE tube, The high-intensity, J. N. ALDINGTON	21
	FLUORINE chemistry, H. J. EMELEÚS	141
	GRAFTING of animal tissues, The, G. M. WYBURN and P. BACSICH	165
B	GRAVITY surveys in submarines, F. A. VENING MEINESZ	170
	INORGANIC chemistry, Structural, W. WARDLAW	66
	ITALY, Science in, EDITORIAL	1
	JOHN DALTON, J. R. PARTINGTON	54
C	LAZZARO SPALLANZANI: founder of experimental physiology, ENRICO TORTONESE	92
	MACROMOLECULES, EDITORIAL	41
	PARASITIC animals and the world's food, G. LAPAGE	27
C	PENICILLINS, Chemical properties and structure of the, E. CHAIN	
	Part I	83
	Part II	153
D	PHOTOGRAPHY, Modern colour, C. E. K. MEES	131
	PICTURES, Scientific methods in the conservation of, IAN RAWLINS	104
	PLANCK, Max, A note on, E. N. DA C. ANDRADE	26
E	PLANT tissue culture, R. J. GAUTHERET	75
	POLARIZATION microscope, The, B. K. JOHNSON	57
	REVIEWS:	
E	Alphabet, The. A Key to the History of Mankind, DAVID DIRINGER	126
	Alsos—The Search for the German Atom Bomb, SAMUEL A. GOUDSMIT	127
E	Applied Plastic Product Design, ROBERT L. DAVIS and RONALD D. BECK	175
	Atom and its Energy, The, E. N. DA C. ANDRADE	175
G	Chemical Constitution of Natural Fats, The, T. P. HILDITCH	40
	Chymia—Annual Studies in the History of Chemistry, TENNEY L. DAVIS, editor-in-chief. Vol. I	175
	Co-operative Research in Industry, D. W. HILL	40
	Detoxication Mechanisms, R. TECWYN WILLIAMS	125
	Dizionario de Chimica, Vol. I, MICHELE GIUA	174
	Electron Microscope, The, V. E. COSSLETT	127
	Évolution de la Notion de Phénomène Physique des Primitifs à Bohr et Louis de Broglie, L ⁱ , JEAN PELSENEER	174
J	Growth of Physical Science, The, SIR JAMES JEANS	80
K	Horology, J. ERIC HASWELL	175
	Integrative Action of the Nervous System, The, SIR CHARLES SHERRINGTON	39
	Introduction to Electrochemistry, An, S. GLASSTONE	176
I	Introduction to Palaeobotany, An, CHESTER A. ARNOLD	80
	Introduction to Textile Finishing, An, J. T. MARSH	39
	ROCKET exploration, A. G. CLARKE	70
	ROYAL Observatory, Greenwich, The, SIR HAROLD SPENCER JONES	9
	SCIENTIFIC information, EDITORIAL	129
A	SOLAR prominences, D. S. EVANS	159
	SYMBOLISM in science, EDITORIAL	81
	SYMBOLS used by the alchemists, Some, DENIS I. DUVEEN	116
	TROPICAL fruits: their storage and transport, C. W. WARDLAW	32

REVIEWS: Page

John Couch Adams and the Discovery of Neptune, W. M. SMART	128
Magnetic Materials, F. BRAILSFORD	127
Methods of Cellulose Chemistry, The, CHARLES DORÉE	39
Newton at the Mint, SIR JOHN CRAIG	39
Nicolaus Copernicus. De Revolutionibus. Preface and Book I. Translated by J. F. DOBSON and S. BRODETSKY	126
Nuclear Physics in Photographs, C. F. POWELL and G. P. S. OCCHIALINI	80
One Two Three . . . Infinity, GEORGE GAMOW	127
Organic Syntheses (Vol. 27), edited by R. L. SHRINER	176
Our Bird Book, SIDNEY ROGERSON and CHARLES TUNNICLIFFE	40
Permo-Triassic Formations, The, R. L. SHERLOCK	126
Photography by Infra-red, W. CLARK	128
Principles of Radar, DENIS TAYLOR and C. H. WESTCOTT	174
Rational Approach to Chemical Principles, A, J. A. CRANSTON	40
Solubilities of Inorganic and Metal Organic Compounds (Vol. I) and Solubilities of the Organic Compounds (Vol. II), ATHERTON SEIDELL	128
Sulfonamides and Allied Compounds, The, ELMORE H. NORTHEY	174
Text-Book of Practical Organic Chemistry, A, ARTHUR I. VOGEL	126

A quarterly review designed to record the progress
of the sciences in the service of mankind

VOLUME VII

JANUARY 1948

NUMBER 25

पुस्तकालय
गुरुकुल कांगड़ी विश्वविद्यालय
Science in Italy

We are glad to announce that, beginning with this issue, an Italian edition of ENDEAVOUR is to take its place at the side of those already published in English, French, Spanish, and German. The occasion is a happy one, for the traditional friendship of the British and Italian peoples, so tragically interrupted by the recent war, has now been cemented anew and holds auspicious promise of future co-operation. Scientists in particular will welcome the revived communion, for few countries have such a brilliant record of scientific achievement as Italy. We cannot here attempt to pay full tribute to this record, but with the launching of ENDEAVOUR in its Italian dress we may fittingly and pleasurably recall a few at least of the innumerable contributions to science made by the countrymen of Galileo.

The story does not begin with Galileo, for the torch of science had burned in Italy long before the sixteenth century. Two or three hundred years earlier the Venetian and Pisan colonies in Constantinople were assimilating the wisdom of the East and transmitting it to their native land; 'many tongued Sicily' was the epitome of Mediterranean knowledge; and the Emperor Frederick II typified his love for experiment by ringing, in 1230, a pike which was long afterwards caught again and presented to the Elector Palatine. This intellectual activity reached its first peak in the person of Leonardo da Vinci (1452-1519), who combined artistic genius with remarkable acumen as biologist, physicist, and mathematician. He was one of the founders of the modern theory of optics, made noteworthy advances in geometry, worked on capillarity, centres of gravity, and frictional resistance, and in the field of anatomy proved himself 'a modern biologist in the disguise of a mediaeval artist.'

Leonardo also paid some attention to statics, but the science of dynamics had yet to be created.

This fundamental step in the progress of natural philosophy was made by Galileo Galilei, who was born of Florentine parents at Pisa on 15th February, 1564. A favourable home atmosphere quickened Galileo's diverse mental aptitudes, and he was well equipped to benefit from the further education he received at a monastery in Vallombrosa and at the University of Pisa. At first he read medicine and philosophy, but he gradually discovered that his true talent lay in mathematics and withdrew from the University without completing his medical course.

Galileo's first important discovery, namely that of the synchronism of the oscillations of a pendulum, was made when he was only 18 or 19 years of age. The discovery was employed by physicians in measuring the rate of the pulse, and went far to make Galileo's name familiar throughout his native land. A few years later, in 1589, he was appointed to the chair of mathematics at Pisa, where he became known as 'the wrangler' on account of his characteristic habit of questioning every assertion—even of so sacrosanct an authority as Aristotle. It was at Pisa that he made his public demonstration of the falsity of the Aristotelian thesis that bodies fall at speeds proportional to their weights—a demonstration which his fellow dons found infamous if not blasphemous, but which in fact may be said to mark the effective birth of modern science.

Conditions at Pisa having become intolerable, Galileo removed to Padua, where he was professor of mathematics from 1592 to 1610. This was the most fruitful period of his life, for during it he not only carried out his great work on dynamics but constructed the first astronomical telescope, with which he observed the satellites of Jupiter and the spots on the sun. He also invented the modern type of microscope and made the first air thermometer. The pitiful story of

his trial by the Inquisition for his support of the Copernican system is too well known to bear repetition, and, though he was forced to make public recantation, the legendary 'Eppur si muove' must yet have remained his unshakable conviction. Blind and wasted by disease in his declining years, Galileo's last days were to some extent cheered by the society and conversation of his disciple Evangelista Torricelli, who succeeded to one of his professorial chairs and is himself remembered as the inventor of the mercury barometer.

A younger contemporary of Galileo was the mathematician and physicist Giovanni Alfonso Borelli (1608-79), professor at Messina and later at Pisa. Borelli was of only moderate ability at mathematics but found a congenial field for applying his knowledge in the investigation of the movements of animals. His great work on this subject, *De motu animalium*, is one of the classics of physiology, and his treatment of the problems of haemodynamics was scarcely improved upon until the middle of the nineteenth century. Borelli's example inspired an even more able physiologist in the person of Marcello Malpighi (1628-94), who was among the first to direct the microscope to biological problems and thus discovered the true structure of the kidney and the details of the circulation of the blood: 'Harvey showed that the blood did sweep through the tissues, Malpighi showed what the tissues were and how the blood swept through them,' so paving the way for basically important later investigations. In the following century, physiology and natural history were further advanced by the accomplished scientist Lazzaro Spallanzani (1729-99), who worked on the processes of reproduction, respiration, and digestion.

Italian major contributions to chemistry came later than those to astronomy, physics, and biology, but one of them had a profound influence upon the progress of the science. It was made by Amedeo Avogadro (1776-1856), professor of mathematical physics at Turin, and is familiar to all scientists as 'Avogadro's hypothesis.' Avogadro, in short, was the first to differentiate clearly between atoms and molecules and, by assuming

that all gases contain equal numbers of molecules (at the same temperature and pressure), to provide chemists with a means of comparing molecular weights. Unfortunately Avogadro's work was long overlooked, and it remained for his fellow-countryman Stanislao Cannizzaro (1826-1910) to bring it into prominence nearly fifty years after its original announcement.

Another essential feature of chemistry, though not of immediate Italian origin, was ultimately based upon Italian discoveries, namely electrochemistry. As is well known, this branch of science was founded by Davy, Berzelius, and Faraday, but its principal tool in early days was the electric battery invented by Alessandro Volta (1745-1827).

Such were some of the achievements of Italian science up to and including the nineteenth century. That the mastery still persists in this twentieth century is abundantly clear—so abundantly, indeed, that far more than the present space would be required to describe it even in outline. One name, of course, stands out above the rest—that of Guglielmo Marconi (1874-1937), whose work on wireless telegraphy and telephony brought him fame and honour in all parts of the world. It cannot be an exaggeration to say that Marconi's researches and inventions have as widely and deeply affected the course of civilization as those of any of the great men of science who preceded or have followed him.

Of the present-day trends of scientific work in Italy this is not the occasion to write fully, but we may mention the fruitful researches in progress there on cosmic rays, electro-acoustics, geophysics, seismology and prospecting, high-frequency technique, nuclear physics, and the development of water power. Scientific research is more highly organized in Italy than in many other countries, a number of specialized institutes working under the *Consiglio Nazionale delle Ricerche*. We hope that the Italian edition of ENDEAVOUR may help in a modest way to further the international co-operation which is the life-blood of science.

Editor: E. J. HOLMYARD, M.A., M.Sc., D.Litt., F.R.I.C.

Deputy Editor: TREVOR I. WILLIAMS, B.A., B.Sc., D.Phil.

Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1

PAUL KARRER

Although the existence of carotenoid pigments has been known for more than a century it is only comparatively recently that their chemistry has been closely investigated. Since 1928 nearly seventy different pigments of this interesting class have been isolated and characterized. This rapid development is due in large measure to the use of chromatography, a modern method of analysis particularly suitable for resolving mixtures of substances which, like the carotenoids, differ relatively little in their chemical and physical properties.

The pigments of the plant and animal kingdoms are of very diverse chemical composition. Many of them, however, can be classified in groups of closely related pigments; the members of such groups usually differ only in the details of their structure. Examples of such natural groups are the yellow flavone and flavonol pigments, the blue and red anthocyanins, the green chlorophylls built up from pyrrole nuclei, red haemins, and bilirubins. Quinone dyestuffs are of the same type. To these large groups of pigments, which impart to living things their pleasing colours, has recently been added the carotenoid group.

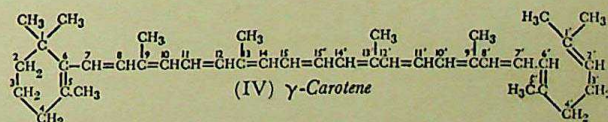
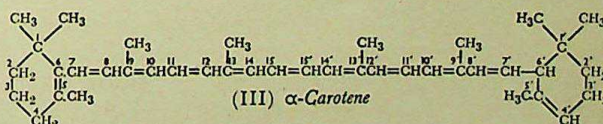
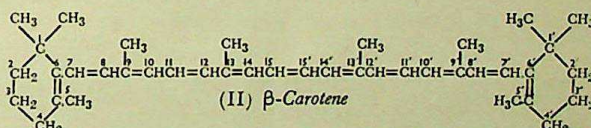
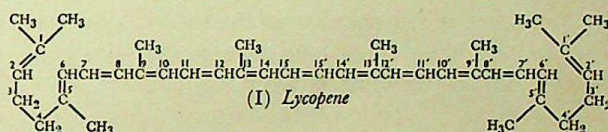
The existence of carotenoids has long been known. Berzelius studied xanthophyll, a mixture of carotenoids. In 1831 Wackenroder isolated carotene for the first time from carrots. For a long time, however, such observations were sporadic. Up to 1928 seven pigments in all had been discovered which appeared to be related to carotene, although they were not definitely proved to be so. Modern carotenoid research began only after 1928. By applying up-to-date methods of investigation it was possible quickly to build up this group of natural pigments. Today it comprises some 65-70 substances.

Carotenoids are present in most plants (with the exception of certain fungi) and probably in all animals, but their concentration is almost always very low. The content of carotenoid pigments (the sum of carotenes and xanthophyll) in green leaves is approximately 0.07-0.20 per cent. (based upon the dry weight of the leaves), and in carrots 0.02-0.13 per cent. In exceptional cases, however, higher pigment concentrations are found. Thus in *Trentepohlia aurea* (common red byssus) about 1 per cent. of the dry weight consists of carotene, and the anthers of many types of lily contain surprisingly large

quantities of xanthophyll epoxide and antheraxanthin (zeaxanthin epoxide).

All natural carotenoids may be regarded as derivatives of the tomato pigment lycopene. By closing the ring of the lycopene molecule on one or on both sides, the three carotenes β -, α -, and γ -carotene are produced (formulae II, III, IV).

These structural formulae were established beyond doubt by means of various decomposition and transformation reactions. Lycopene and its closed-ring relations, β -, α -, and γ -carotene, contain forty carbon atoms and may be regarded as compounded of eight isoprene residues. One of



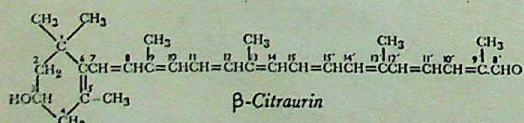
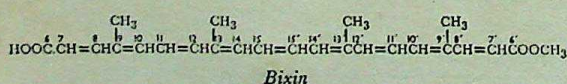
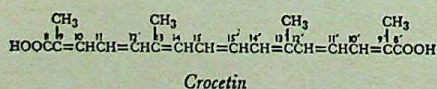
their characteristic features is the large number of conjugated double bonds forming their chromophore groups. The carotenoids are thus a subdivision of the polyene pigments.

The other carotenoids of which the structures have been established can without exception be regarded as derivatives of the four hydrocarbons formulated above. They are derived from them by the introduction of hydroxyl, carbonyl, epoxide, and methoxyl groups, or by partial hydrogenation or oxidation.

A few of the more important derivatives of this kind are summarized in the following table:

Derivatives of:	
Lycopene	Lycoxanthin (3-oxylicopene) Lycophyll (3,3'-dioxylicopene)
β -Carotene	Cryptoxanthin (3-oxy- β -carotene) Zeaxanthin (3,3'-dioxy- β -carotene) Antheraxanthin (zeaxanthin-5,6-epoxide) Violaxanthin (zeaxanthin-5,6,5',6'-diepoxide) Citroxanthin (furanoid monoxide of β -carotene) Auroxanthin (furanoid zeaxanthin dioxide) Aphanin (3-keto- β -carotene) (?) Rhodoxanthin (3,3'-diketo- β -carotene) Astacin (3,4,3',4'-tetraketo- β -carotene) Astaxanthin (3,3'-dioxy-4,4'-diketo- β -carotene) Capsanthin Capsorubin
α -Carotene	Xanthophyll (3,3'-dioxy- α -carotene) Xanthophyll-5,6-epoxide α -Carotene-5,6-epoxide Flavoxanthin (furanoid xanthophyll epoxide) Chrysanthema-xanthin (furanoid xanthophyll oxide)
γ -Carotene	Rubixanthin (3-oxy- γ -carotene) Rubichrome (furanoid rubixanthin oxide) Eschscholtz-xanthin (dioxy- γ -carotene) (?)

The following compounds are examples of natural pigments which may be regarded as oxidation products of various carotenoids containing forty carbon atoms:



From a comparison of the last three structural formulae with those of lycopene and of β -, α -, and γ -carotene, it is easy to see which carbon atoms of the hydrocarbons have been preserved in the crocetin, bixin, and β -citaurin, and those which have been removed by oxidation.

It is often difficult to isolate and purify the carotenoids. It is primarily to chromatography that we owe our present ability to separate quantitatively such closely related substances as α - and β -carotene, which differ only in the position of one double bond, or to extract all the γ -carotene from a mixture of α -, β -, and γ -carotene in which the last is present to the extent of only 1 or 0.1 per cent. The process of separation by chromatography was invented some considerable time ago (1906) by the botanist Tswett. It consists in allowing a solution of the mixture of substances which it is desired to separate to run through an adsorption column, which is afterwards washed with the solvent. This subsequent washing—development of the chromatogram—continuously elutes the adsorbed substances and precipitates them again lower down on the column of adsorbent. As the elution of the more strongly adsorbed components takes place more slowly than the elution of the substances which are less strongly adsorbed, this process of development effects a sharp separation of the individual constituents of the mixture.

Twett himself used this process for the separation of carotenoids, although only for qualitative analysis. It is only recently that chromatography has been used for the purification and quantitative separation of carotenoids on a preparative scale. There are numerous mixtures of carotenoid pigments which, but for this efficient method, we should not today be able to separate.

The tenacity with which the carotenoids adhere to the adsorption column, which may consist of aluminium oxide, calcium hydroxide, calcium carbonate, or zinc carbonate, depends first and foremost on the functional groups present in the pigment molecules. Carboxyl and hydroxyl groups raise the power of adsorption very strongly, and in proportion to their number. Thus carotenoid carboxylic acids and di- and poly-oxycarotenoids will be found in the upper part of a Tswett adsorption column; lower down will come mono-oxy compounds, ketones, aldehydes, and so on. Finally, at the bottom, come the hydrocarbons.

Figure 1 shows the appearance of a mixture of

(a)



FIGURE 1 - Chromatographic separation of lycopene (a), β -carotene (b), and α -carotene (c).



FIGURE 2 (reading from left to right) - Solutions of various carotenoids in carbon disulphide.

1. Auroxanthin, a carotenoid with 7 conjugated and 2 isolated double bonds (equivalent to 8 conjugated double bonds).
2. Dihydro- β -carotene, a carotenoid with 10 conjugated double bonds.
3. β -Carotene, a carotenoid with 11 conjugated double bonds.
4. Lycopene, a carotenoid with 11 conjugated and 2 isolated double bonds (equivalent to 12 conjugated double bonds).
5. Dehydrolycopene, a carotenoid with 15 conjugated double bonds.



FIGURE 3

1. β -Carotene crystallized from petroleum ether.
2. α -Carotene crystallized from petroleum ether.
3. Lycopene crystallized from petroleum ether.
4. Xanthophyll crystallized from a mixture of methyl alcohol and ether.
5. Zeaxanthin crystallized from a mixture of methyl alcohol and ether.
6. Violaxanthin crystallized from a mixture of methyl alcohol and ether.

β -carotene, lycopene, and α -carotene after chromatographic analysis.

The absorption spectra of the carotenoids provide a valuable means of identifying them and of checking their purity. Almost all carotenoid pigments have three sharply defined maxima in the visible part of their spectrum. The position of these maxima is determined mainly by the chromophore present, i.e. by the number of double bonds in the respective pigment. Each new carbon double bond entering into the conjugated system of double bonds displaces the absorption maxima towards longer wavelengths by approximately the same amount, namely 200–220 Å.

The absorption conditions in the ultra-violet range are somewhat less regular and more dependent on the other constitutional characteristics of the pigment. Figure 4 shows absorption curves for a few of the more important carotenoid pigments.

Other chromophores, such as $=C=O$ and $-COOH$ groups, cause a deepening of the colour, particularly when they are associated with the system of conjugated double bonds. The effect of a carbonyl group under these circumstances is a displacement of the absorption maxima in the visible spectral range by about 400 Å. Much more frequently, however, the conjugated system

of carbon double bonds itself is almost entirely responsible for the colour. Carotenoids are now known in which the number of double bonds varies from 6 to 15. The colours of their solutions range correspondingly from yellow to violet, as shown in figure 2.

All carotenoid pigments crystallize very readily. In reflected light the crystals appear yellow, orange, or red; some (astacin, for example) are almost black, depending upon the composition of the substance and the development of the crystals. By transmitted light, all crystals of carotenoids appear yellow, orange, or red. The crystals are often dichroic. Figure 3 gives an indication of their shapes and colours.

The interest of modern research on carotenoids is due in part to the physiological importance of some individual members of the group. Carotenoids are formed mainly in plants, and it is doubtful whether animal organisms are capable of bringing about more than slight changes in the molecules of these pigments. No facts are at present known which would justify the assumption that a carotenoid found in the organism of an animal might have been synthesized there from simpler substances. In spite of the fact that the carotenoids are thus primarily vegetable pigments, very little is known regarding their significance in the

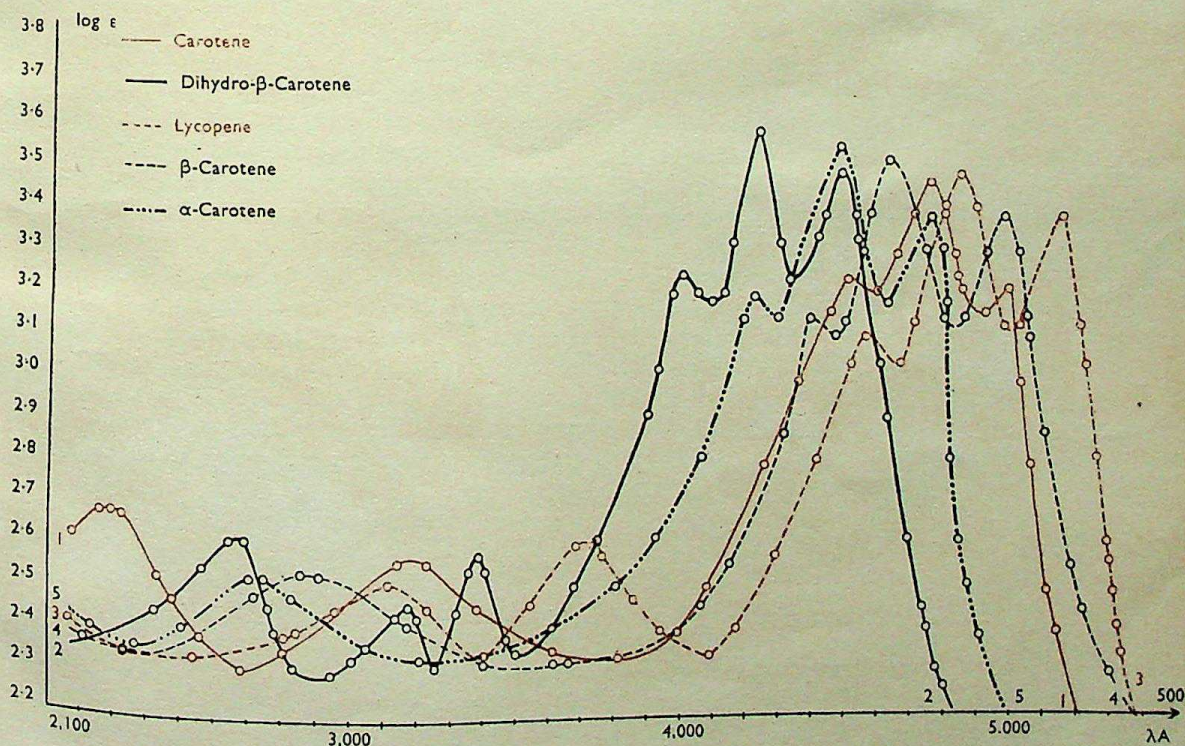


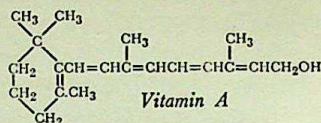
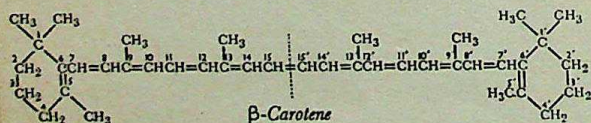
FIGURE 4 - Absorption spectra of some carotenoids in hexane solution.

life of plants. β -Carotene (and to a lesser extent α - and γ -carotene as well) and xanthophyll are present in every green leaf in quantities roughly proportional to the chlorophyll content of the leaf. The question whether these two yellow pigments take part in the assimilation process or in the respiration of the plant has often been discussed, but no satisfactory answer has yet been found.

Kuhn and Moevus assert that crocin (crocin digentiobiose ester) and *trans*- and *cis*-crocin play a part in the reproduction of the unicellular alga *Chlamydomonas eugametos f. simplex*. Crocin can bring about flagellum-formation in the gametes of these plants, and mixtures of *trans*- and *cis*-crocin can then transform the mobile gametes into male or female gametes. The ratio of *cis*- to *trans*-crocin determines whether male or female gametes are formed. These experiments require further confirmation.

The widespread diffusion of carotenoid epoxides throughout the vegetable kingdom and the ease with which they give up their oxygen has led to the surmise that in certain vegetable organs these substances may act as oxygen carriers, but it has not yet been possible to confirm this hypothesis.

We have more exact information regarding the importance of some carotenoids to animal organisms. It has been proved that carotene acts as vitamin A, a fact first established by H. Steenbock and by H. von Euler. Later it was shown that this action of carotene is due to the fact that in animal organisms it is transformed into vitamin A (Moore). It is thus a pro-vitamin A. When the structure of the carotenes and of vitamin A were established, the connections between them were more comprehensible. The transformation of β -carotene into vitamin A is possible by splitting the molecules into identical halves:



β -Carotene is not the only pigment of this group of compounds which possesses the characteristics of a pro-vitamin A. The same physiological effect is exercised by all those pigments which contain in their molecules at least one of the groups comprising half the β -carotene molecule. These natural pro-vitamins A, which are present in plants, are the following:

- α -carotene
- β -carotene
- γ -carotene
- α -carotene-5,6-epoxide
- citroxanthin (furanoid monoxide of β -carotene)
- cryptoxanthin (3-oxy- β -carotene)
- myxoxanthin
- aphanin (3-keto- β -carotene) (?)
- echinenone
- torularhodin.

A large number of synthetic pro-vitamins A have been prepared.

Carotenoids are also present in the eyes of human beings and animals, and appear to be of importance in the process of vision. Visual purple, or rhodopsin, is today thought to be a compound of a type of albumin with the carotenoid retinin. The latter is probably the aldehyde corresponding to vitamin A. When light acts on visual purple, retinin is liberated and transformed into vitamin A. In the dark, the visual purple is reconstituted from vitamin A and retinin (G. Wald). We know even less, however, about the part played by other carotenoid pigments which have been detected in eyes.

The Royal Observatory, Greenwich

SIR HAROLD SPENCER JONES

The Greenwich meridian was adopted, at an international conference held in 1884, as the prime meridian of the world. At the same conference a system of time zones based upon Greenwich Mean Time was recommended. These decisions were a recognition of the great services the Observatory had rendered to navigation. The Observatory has also carried out fundamental astronomical research in many other directions. Its current removal to Herstmonceux Castle, in Sussex, promises an opportunity for enhancing an already great reputation.

The Royal Observatory, the oldest scientific institution in Great Britain, was founded by King Charles II in 1675 for the practical purpose of assisting navigation. At that time there was no method of finding the longitude at sea. The suggestion had been made that the longitude could be found by measuring the distances of the Moon from adjacent bright stars. When this was brought to the notice of the King, he referred it to a committee of scientific men for a report. The report was prepared by the Rev. John Flamsteed (1646-1719), who had acquired a considerable reputation as a practical astronomer. It pointed out that the positions of the Moon given by the best tables differed as much as one-third of a degree from the true positions, while the star catalogue of Tycho Brahe, which was nearly a hundred years old, was erroneous and incomplete. The method was in theory correct but could not be applied in practice 'till both the places of the fixed stars were rectified, and new tables of the Moon's motion made, that might represent her place in the heavens to some tolerable degree of exactness; for which a large stock of very accurate observations, continued for some years, was altogether requisite.'

Charles II decided to found an observatory where the required observations could be made, and to appoint Flamsteed as the astronomer to do the work. He provided a site on the highest ground in his park at Greenwich and appointed Sir Christopher Wren as the architect. The observatory was erected at a cost of £520, defrayed by the sale of spoilt gunpowder. There Flamsteed began his observations in 1675. His position was not an easy one, for he was provided neither with instruments nor with assistants. His friend and patron, Sir Jonas Moore, presented him with two clocks by Tompion, and a large iron sextant, with which, working single-handed, he made 20,000 observations in thirteen years. But these observa-

tions gave only relative positions. It was not until 1689 that Flamsteed was able to install a large mural arc and to derive absolute positions. In all, he spent upwards of £2,000 above his meagre salary of £100 a year in furnishing instruments and in hiring assistants and computers.

Flamsteed's observations were planned with a careful attention to accuracy. They are, in fact, the earliest from which the phenomenon of aberration is clearly deducible. He introduced new methods into practical astronomy, many of which are in use today, and an immense mass of computations was carried out in a systematic and orderly manner to correct the theories and to improve the tables of the Sun, Moon, and planets, and to elucidate intricate points in practice and theory. The collected observations, including his great star catalogue of nearly three thousand stars, were printed at his own expense as the *Historia Coelestis Britannica*. He died in 1719, when much of the printing still remained to be done. This work was the first great contribution to science given by the Greenwich Observatory to the world.

Edmond Halley (1656-1742), the Savilian Professor of Geometry at Oxford, was appointed Astronomer Royal in succession to Flamsteed. Halley was a man of great originality and versatility, eminent in many branches of science. His authority in astronomical matters was so great that, although he was 63 years of age, no other appointment was possible. He found the Observatory devoid of equipment, for Flamsteed's instruments, which he had paid for out of his own pocket, had been removed by his widow. Halley obtained a grant of £500 from the Board of Ordnance, with which he procured an 8 ft. mural quadrant and a small transit instrument. In order to improve the current tables of the Moon for the purpose of determining longitudes, he planned to observe the Moon through a complete

revolution of its nodes—nearly nineteen years—a task which, in spite of his advanced age, he completed. His observations and his general astronomical tables were published in 1749.

Halley was succeeded by the Rev. James Bradley (1693–1762), the Savilian Professor of Astronomy at Oxford, a great practical astronomer and a skilful observer. Bradley had already acquired fame by his discovery in 1728 of the phenomenon of the aberration of light, from observations with a 12 ft. zenith sector of the zenithal star, Gamma Draconis. He continued his observations of this star through a complete revolution of the Moon's nodes, and in 1748 announced the discovery of the nutation of the Earth's axis, the cause of which he correctly explained.

Bradley added two mural quadrants and a transit instrument to the equipment, the cost being defrayed out of a grant of £1,000 provided by the Admiralty from the sale of old naval stores. His zenith sector was also bought for the Observatory out of the grant. With these instruments some 60,000 observations of the fixed stars were made between 1750 and 1762, with the aid of one assistant. Bradley determined the laws of atmospheric refraction and was the first to introduce corrections for the temperature of the air and for the height of the barometer. His observations surpassed in accuracy any made up to his time: they are the earliest which are accurate enough to be of use to the astronomers of today.

The Rev. Nevil Maskelyne (1732–1811) was appointed Astronomer Royal in 1765, on the death, after a brief tenure of office, of Bradley's successor, the Rev. Nathaniel Bliss. Maskelyne took a great interest in practical navigation. He convinced himself by trials at sea that the method of lunar distances had at length become a practicable one, and that, with the aid of the new tables of the Moon prepared by Tobias Mayer and published at the expense of the Board of Longitude, it was capable of determining the longitude with satisfactory accuracy. Maskelyne provided a most valuable aid to navigation in the preparation of the *Nautical Almanac*, first published for the year 1767. He continued to produce it annually for forty-four years until his death. The invention of the marine chronometer by John Harrison, a Yorkshire carpenter (1693–1776), had provided a practical solution of the longitude problem, but astronomical observations were still required as a check on the error and rate of the chronometer.

Various improvements to the instruments and

in the methods of observation were made by Maskelyne. He gave special attention to observations of the Moon to obtain data for the correction of Mayer's Lunar Tables. The Sun, planets, and thirty-six fundamental stars were regularly observed. His determination of the proper motions of these stars provided the data used by William Herschel to derive the motion of the Sun in space. In 1774 Maskelyne made the first measurement of the density and mass of the earth, from observations of the deflection of the plumb-line to the north and south of the mountain of Schiehallion. A mean density of 4.7 times that of water was obtained, a value which agrees with the true value within the uncertainty of the estimate of the mass of the mountain.

The progressive improvement in the accuracy of observation was continued under John Pond (1767–1836), who succeeded Maskelyne in 1811. The construction of a new mural circle, ordered by Maskelyne, was completed in 1812, and a 5 in. transit instrument replaced Bradley's small one in 1816. Pond introduced the use of the mercury horizon for determining instrumental flexure and the position of the nadir point. His catalogue of the positions of 1,112 stars, completed in 1833, was the most valuable contribution of the period to positional astronomy.

In 1818 the control of the Observatory passed from the Board of Ordnance to the Board of Admiralty, and in 1821 the charge of chronometers used in the Royal Navy was transferred to the Observatory. The first public time-signal was inaugurated in 1833; it consisted in the dropping of a time ball at 1 o'clock p.m. daily from the top of a mast erected on the Wren building. Ships in the adjacent reaches of the river and in the docks were thereby enabled to regulate their chronometers.

During the later years of his tenure of office Pond's health was failing, his First Assistant was inefficient, and the routine work of testing chronometers occupied an unduly large portion of the time of the small staff. The Observatory consequently fell into a state of disrepute. When Pond resigned in 1835, George Biddell Airy (1801–92) was called in to reorganize the Observatory. Airy had been elected Lucasian Professor of Mathematics at Cambridge in 1826, and Plumian Professor of Astronomy, with the direction of the new Cambridge Observatory, in 1828. A man of rigid routine, a strict disciplinarian, with wide interests and of exceptional ability, he was the ideal man for the task. During his long tenure

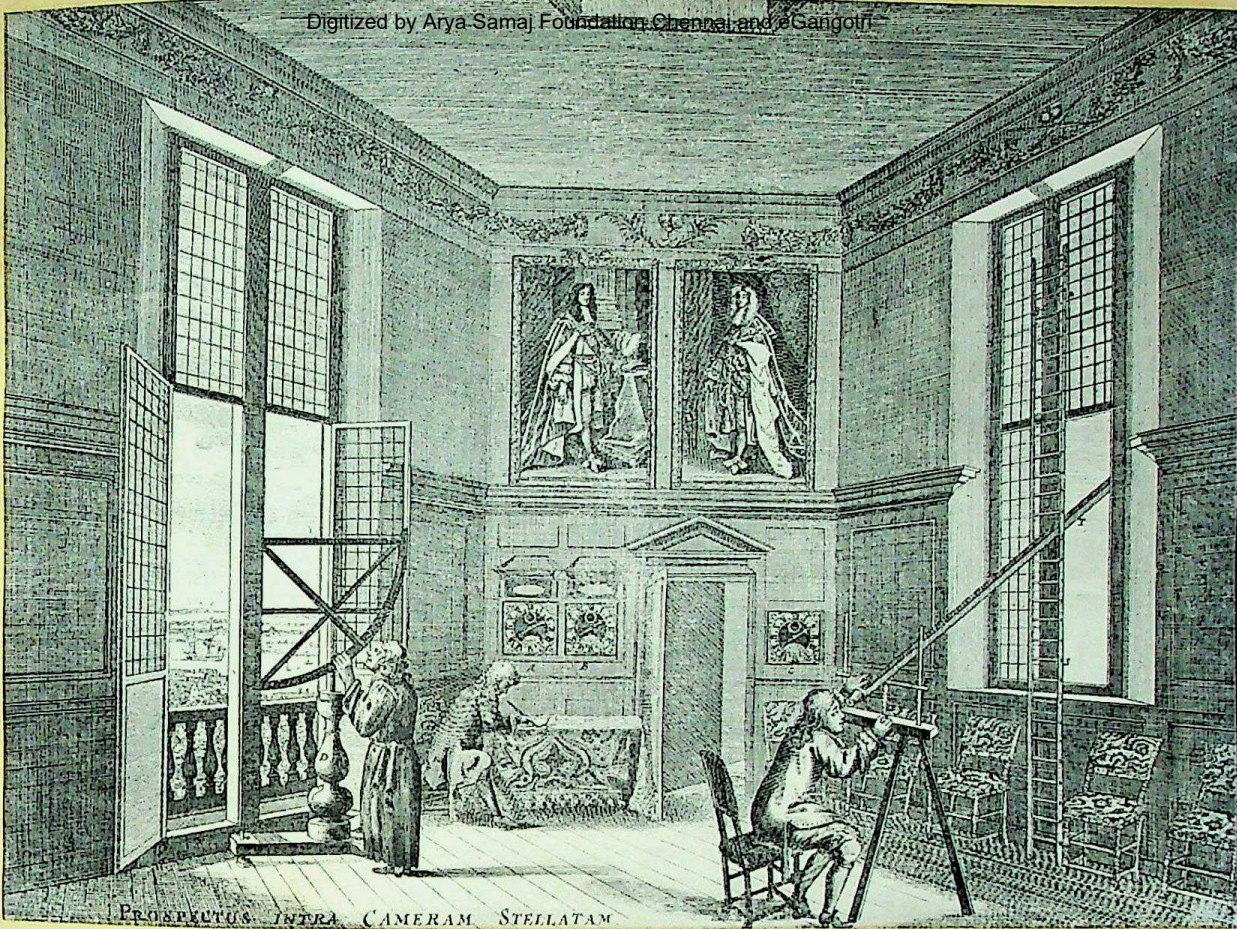


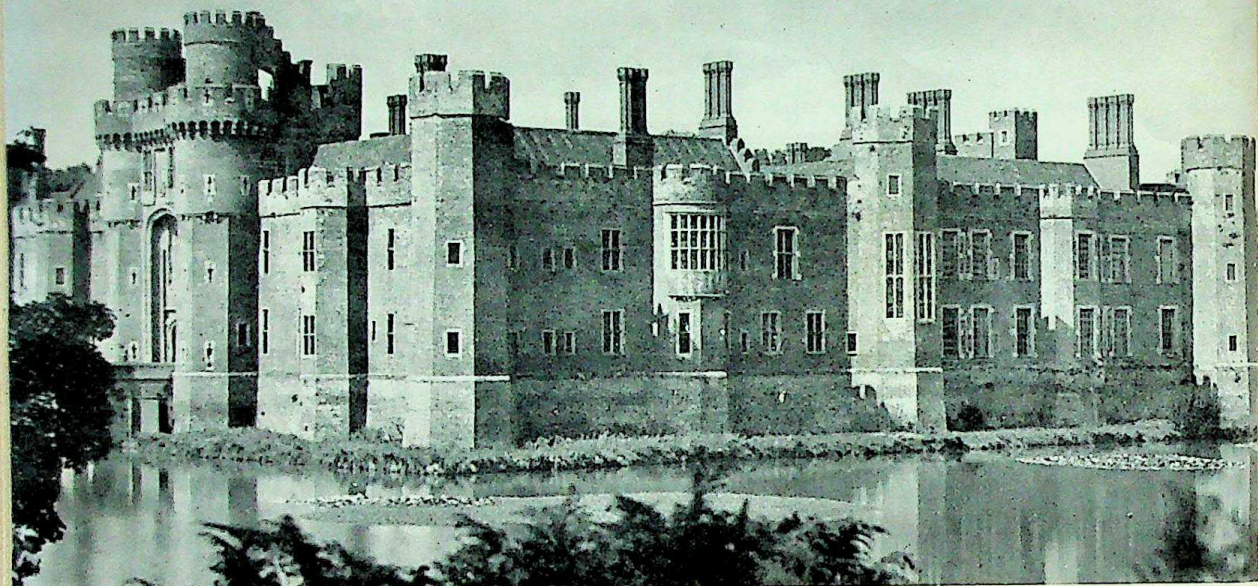
FIGURE 1 - Interior of the Octagon Room in Flamsteed's time, showing the two Tompion clocks (A and B) and the quadrants with which most of the observations from 1675 to 1689 were made.



FIGURE 2 - The Rev. John Flamsteed, Astronomer Royal, 1675-1719.

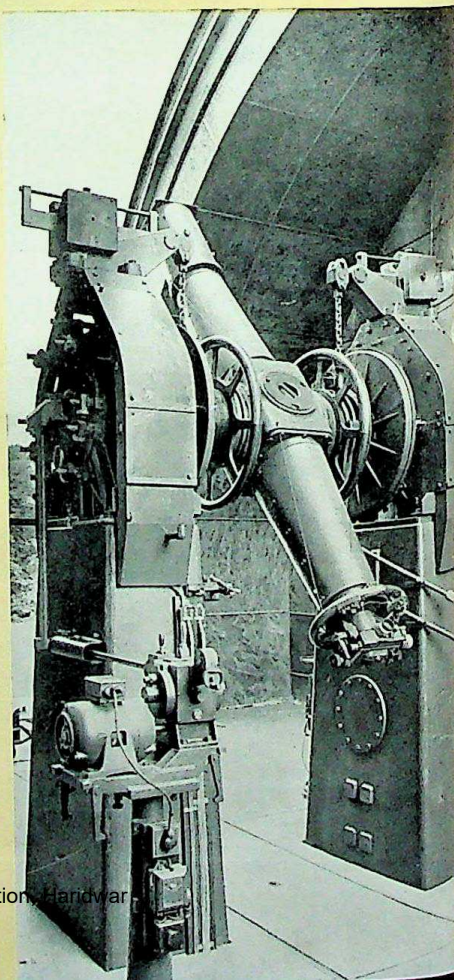
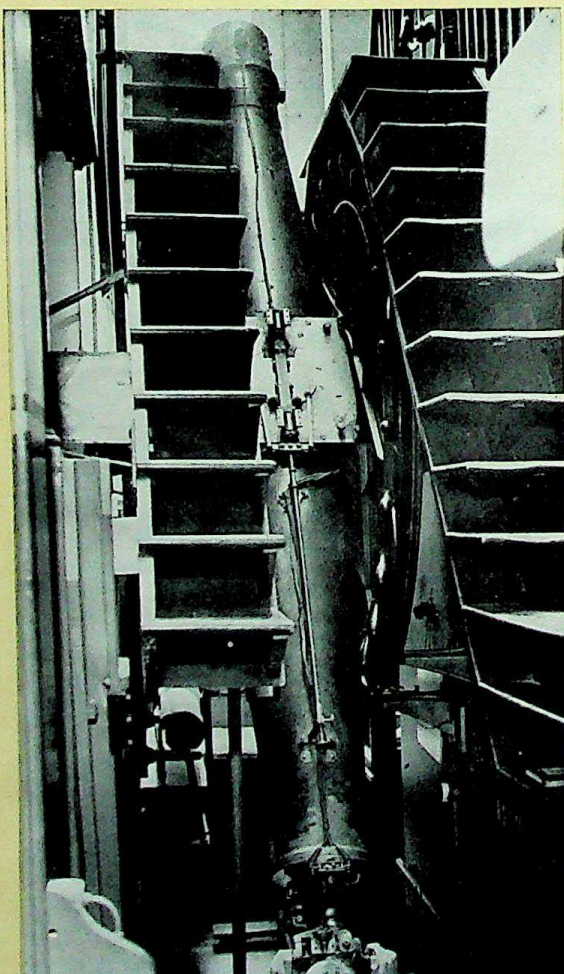


FIGURE 3 - Sir George Airy, Astronomer Royal, 1835-81.



(above) - Herstmonstereury Castle, the future Royal Observatory.

(right) - The 26 in. photographic and the Yapp 36 in. slitless spectrograph.



tion, Haridwar

of office the Observatory acquired a great reputation: he became the most commanding figure in the astronomy of his time, and was called in to advise the Government on a great variety of matters. He was, for instance, chairman of the Commission responsible for the restoration of standards of length and weight after their destruction in the great fire at the Houses of Parliament. On the development of iron ships he devised methods, which are still in use, for the correction of ship's compasses. He also prepared the report on the gauge to be adopted as standard by railways.

The meridian observations, which formed the traditional work of the Observatory, were continued systematically and with great energy, special attention being paid to the planets, the observation of which had been much neglected by Pond. An altazimuth instrument was installed in 1847 to enable observations of the Moon to be obtained in parts of her orbit where she could not be observed on the meridian. A large transit circle, to do the work previously done by the transit instrument and the mural circle, was designed by Airy and brought into use in 1851. This famous instrument, which was later to define the prime meridian of longitude, has continued in use to the present time: more than 650,000 observations of the Sun, Moon, planets, and stars have been made with it. A natural development of the meridian work, made possible by the introduction of telephonic communication, was the distribution of time to the Post Office, to the railways, and to the Admiralty dockyards. Greenwich Mean Time

was not adopted as the legal time of Great Britain until 1880. Before that date local mean time was often used, but the growth of railway communications had resulted in the general use of G.M.T., which was popularly known as Railway Time.

Airy soon saw the need for the extension in new directions of the work of the Observatory, which had hitherto been confined to positional astronomy. A magnetic and meteorological department was established in 1840. At first, magnetic observations were usually made at intervals throughout the day and night, but in 1848 continuous photographic registration was introduced. The observations were continued at Greenwich until 1923, when the electrification of the local railways necessitated the removal of the instruments to a new site, a separate magnetic observatory being established at Abinger in Surrey. The Royal Observatory has the longest continuous series of magnetic observations in the world.

The association between terrestrial magnetic disturbances and sunspots suggested the need for these related phenomena to be studied together. Accordingly, in 1873 a photoheliograph was installed for the regular daily photography of the Sun. Similar observations were also initiated at the Cape Observatory (South Africa), the photographs being sent to Greenwich. The combined series provides a practically continuous record of the Sun's surface, which has proved invaluable in a variety of investigations.

Two equatorial refractors were added to the equipment; the Mertz 12 $\frac{3}{4}$ in., added in 1858, was a large instrument at that time. Observations

of comets, double stars, and of planetary markings were made. With the birth of astrophysics, a spectroscope was added in 1874 for visual observations.

The new developments in the work, and the great activity under Airy's regime, had involved a corresponding increase in staff. In the first 150 years of its existence the work of the Observatory had been largely the personal work of the Astronomer Royal. Now, however, it was on the way to becoming a large institution, with a variety of programmes of work in which the whole staff co-operated. It is possible to refer only to some of the

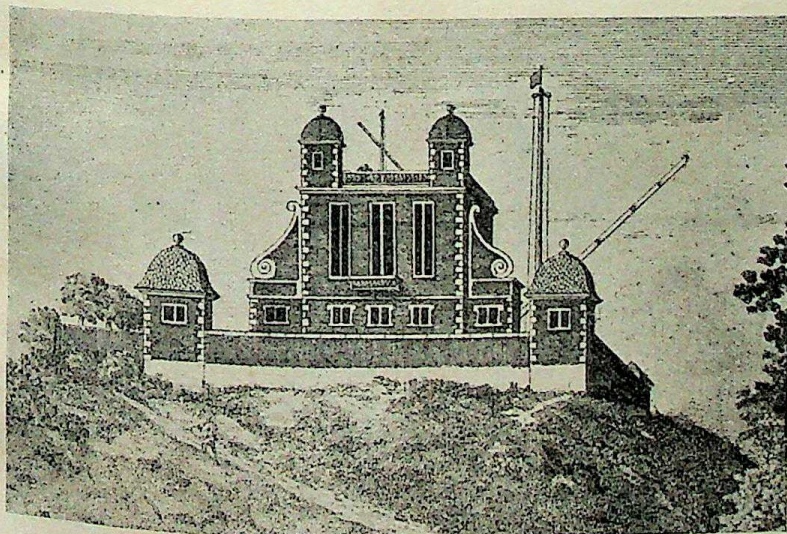


FIGURE 6 - View of the north aspect of the observatory in Flamsteed's time.

principal developments since 1800, under the administration of Sir William Christie (Astronomer Royal 1881-1910), Sir Frank Dyson (Astronomer Royal 1910-33), and the writer.

The application of photography to astronomy has led to great and rapid developments. One of the first projects to which photography was applied was the *Carte du Ciel*—a photographic chart and catalogue of the whole sky, in which a number of observatories co-operated, using similar astrographic telescopes of 13 in. aperture. Greenwich assumed responsibility for the cap of 25° radius round the north celestial pole. This region of the sky has become peculiarly a Greenwich region, many programmes of observation having been concentrated on providing additional information about the stars in it. The region was completely rephotographed after about twenty-five years in order to determine the proper motions of the stars. The distances of many of the stars have been measured with the 26 in. refractor, presented, together with a 30 in. reflector, by Sir Henry Thompson in 1894.

A 28 in. visual refractor was added in 1894, and has been used mainly for double star observations. In 1931 Mr W. J. Yapp presented a 36 in. reflector, together with a slitless spectrograph and a slit spectrograph with one-prism and three-prism dispersions. These have been used for the measurement of the colour temperatures of stars, and for general spectrographic investigations.

In 1884 the State Department of the United States convened a conference in Washington to obtain international agreement on the choice of a prime meridian, and the establishment of a zone time-system based on that meridian. The Greenwich Observatory had been so long and so closely concerned with the needs of navigation that no alternative to the meridian of Greenwich was seriously considered. The meridian through the centre of the Airy transit instrument was adopted as the prime meridian, and a system of time zones based on Greenwich Mean Time was recommended and is now in almost universal use.

Meridian observations have continued to be an important part of the work of the Observatory. To meet the requirements for higher precision, a new reversible transit circle was installed in 1936. A wider dissemination of accurate time was made possible by radio. The British Broadcasting Corporation's 'six pips' time signals were inaugurated in 1924. Special rhythmic time signals for navigational use have been sent out twice daily from the Rugby wireless station since 1927.

The signals, of a wide range, enable the navigator to check his chronometers, and have made the old method of lunar distances obsolete. The Post Office 'speaking clock,' installed in 1936 and controlled by hourly signals from the Observatory, has made Greenwich time available by telephone everywhere in Great Britain. At the same time the precision of the time service has been greatly improved to meet practical requirements. The Observatory now bases its time entirely on quartz crystal clocks, eighteen of which have been installed. A 10 in. photographic zenith tube, of special design, is now under construction and will greatly increase the accuracy of time determination.

Expeditions have been sent from time to time to various parts of the world to observe total eclipses of the Sun. Mention may be made of the expedition to Brazil for the eclipse of 29th May, 1919, which provided the first confirmation of Einstein's prediction of the bending of rays of light passing near the Sun.

Greenwich was a village in the country when the Observatory was established in 1675. As a result of the growth of London, particularly during the last few decades, the Observatory is now surrounded by closely built-up areas, with many industrial plants in its vicinity. The smoky atmosphere, and the bright sky at night from the glare of London, have caused a progressive deterioration in the conditions for astronomical observations. The installation of larger and more powerful telescopes at Greenwich could not be justified. In spite of the ties of long tradition, the removal of the Observatory from Greenwich had become necessary if it were to continue to make important contributions to the advancement of astronomy. Proposals were submitted to the Admiralty, and as a result, after a large number of possible sites had been investigated, Herstmonceux Castle in Sussex (built in 1440), together with some 370 acres of surrounding land, has been acquired. The first stages of the removal of the Observatory to Herstmonceux are now in progress. The Government has agreed to provide a large reflector of 100 in. aperture, the use of which is to be shared between the Royal Greenwich Observatory (by which name the Observatory will in future be known) and the other observatories of Great Britain. This powerful new instrument will in due course be erected at Herstmonceux. After 272 years at Greenwich, a new era is now opening in the long history of the Observatory, rich with opportunity and promise for the future.

British coinage and coinage alloys

W. A. C. NEWMAN

The manufacture of coins presents metallurgical problems of great interest, because for historical and economic reasons it is frequently necessary to use alloys which differ considerably from those which would be chosen on the ground of suitability. The assaying of coins also presents difficulties, as some of the alloys used show the phenomenon of segregation, which results in variation in the composition of the alloy in different parts of the casting.

The history of coinage is long and intricate, but the underlying principles are comparatively simple. One of the first methods of exchange was by bartering, but fraud on the one hand, and inconvenience on the other, tended to bring it into disrepute. It should be borne in mind, however, that bartering is not unknown between both nations and individuals at the present time, and that the actual passage of money is rarely necessary in carrying out large international transactions.

Originally, things that had nothing in common by which their value could be assessed proved difficult to exchange, and the accumulation of unwanted goods by anyone fortunate enough to have much of which to dispose was a source of inconvenience and embarrassment. The transition, therefore, to a system in which values were expressed in quantities of some common article—such as shells or notched sticks—was naturally easy.

Such primitive currencies simplified many of the exchange problems, as they made it possible to decide upon and to maintain constant values for commercial goods. But the fragility of objects such as shells quickly led to a search for more permanent materials for currency, so that assets should not—in a very real sense—be ‘wasting’ ones. Flints, hard rocks, and native metals were tried in turn, but there was always a danger of serious inflation when these commonly occurring materials were used. With the discovery of electrum—an alloy of gold and silver—and of deposits of other durable metals such as gold, silver, and copper (the latter often mixed with baser metals) the age of metallic currency may be said to have started.

There still remained the necessity of indicating the value of the crude and irregular lumps of metal originally used. It became customary to fashion the lumps into regular shapes and weights,

such as disks or squares, and to have not only small numerical signs upon them but also designs which could not easily be copied.

There followed the gradual evolution of the present system, in which the weights and compositions of coins are subject to legal control and the obverse and reverse designs are carefully chosen to indicate value and country of origin. It has been said with truth that since the thirteenth century the designs of the coinage of civilized countries have always fairly represented the artistic culture of the periods in which the coins were struck.

In ancient Egypt, and later in the Roman Empire, copper was the standard of value. The Roman pound weight of copper was the *as*, and the Treasury was called the *Aerarium*, or copper store. By the middle of the third century B.C. silver also had become a medium of exchange. The silver unit was the *sestertius*, and later the *denarius*, equivalent to 10 sesterces. The Roman term *denarius* survives in abbreviated form in the British abbreviation *id.* for one penny. Expansion of trade and increase in wealth rendered the silver coins inadequate, and gold, in the form of ingots, became the medium for larger transactions, copper and silver becoming merely token coinages.

These three principal metals were initially used in their natural state or in a crudely refined condition. They derived part of their property of durability from the presence of impurities. Today alloys are preferred to pure metals for the same reason, nickel alone being used unalloyed for coinage purposes. Pure zinc and aluminium have, however, also been tried, despite their inherent disadvantages.

It was not until the thirteenth century that there was a uniform gold coinage in Britain, although foreign gold pieces had previously circulated as gold bullion. The famous gold stater

of Philip of Macedon, the bezants of Constantinople and of the Greek Empire, and the florins of Florence are typical of these foreign products.

From the first introduction of native gold coins in Britain, however, there was no interruption in their production until 1917, though there were many changes in fineness, weight, and designation.

At the outset, the coins of Henry III were almost pure gold, and the denomination was that of a gold penny. Later the name changed to florin, noble, rose noble, crown, sovereign, and angel. It changed back to sovereign in Elizabeth's reign, to guinea from the time of Charles II to that of George III, and again to sovereign in 1816, when gold became the only standard of value. The fineness was established at 22 carats, or 916.6 parts per 1,000, in the time of James I, and it remained at that figure in all succeeding reigns. Twenty pounds weight (troy) of gold of this fineness coined into 934 sovereigns and one half-sovereign.

In the earlier days the metals alloyed with gold were silver and copper. The latter was added

intentionally in order to make a workable and hard-wearing metal; the former was present because of the inadequacy of the refining processes then known. The introduction of the Miller chlorine refining process in 1867 was effective in removing silver from the gold, and from that time onwards copper alone was the alloying metal.

The history of the silver coinage in Britain is one of many changes. The fineness of sterling silver as 925 parts per 1,000 was established in Saxon times. The term 'sterling' itself is derived from the Easterlings, who were people of the Low Countries trading in Britain, and who may very possibly have been employed in the making of coins. Afterwards the term 'sterling' became synonymous with standard silver, but it also assumed a second meaning signifying the international currency value of British credit. The term 'sterling silver' is still used, particularly to describe silver wares which are hall-marked as being of the correct 925 standard.

The principal weight employed for weighing gold and silver coin is the troy pound. This has been used since 1527. It is divided into ounces, pennyweights, and grains, a pennyweight being 24 grains. Previously there had been other units, such as the Tower Pound, the Goldsmiths' Pound, and the Moneyers' Pound, one-twelfth of which, or 1 oz., contained only 450 grains, as compared with the 480 grains of the present troy ounce. The pennyweight in this case was only $22\frac{1}{2}$ grains. In Norman times the pound weight of sterling silver was coined into 240 pence. This was the origin of the term 'pound sterling'; nowadays, however, it no longer describes a pound of sterling silver but the purchasing power of a pound note.

Depreciation of the silver coinage began in the time of Edward I (1279), when 243 pence instead of 240 were allowed to the troy pound. Henry VIII increased this to 576 pence, and reduced the fineness to $333\frac{1}{3}$, with great profit to his own purse. In the succeeding reign of Edward VI (1550) a minimum was reached when the fineness was allowed to touch 250 parts per thousand. Elizabeth, however, very wisely raised it again to 925, at which figure it remained until 1921. By the time this permanent change took place the relation of money to commodities had undergone such variations that it was no longer possible to revert to the older relation of twenty shillings to the pound troy. It had to continue at a higher figure, first at 60 shillings, then at 62 shillings, at which it

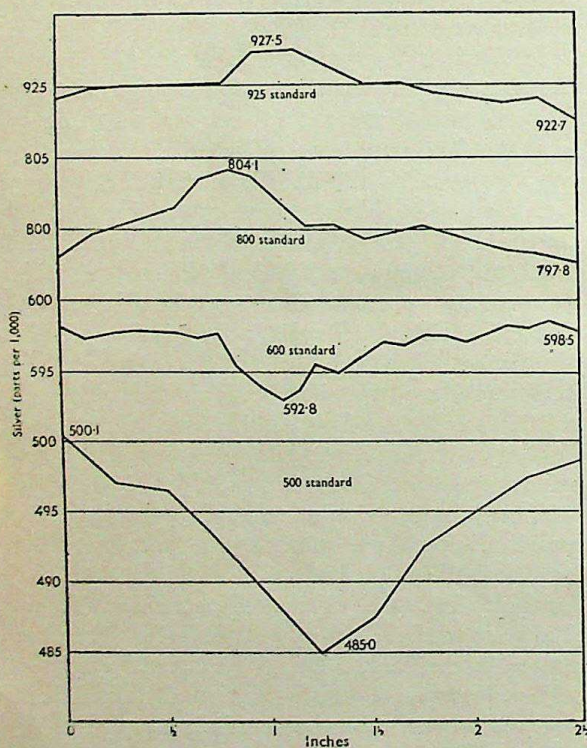


FIGURE 1 - The diagrams above show how the phenomenon of liquation can affect the composition of a silver-copper alloy at different points across a bar $2\frac{1}{2}$ in. wide. The effect is much more marked with the 500 alloy, introduced in 1920, than with the old 925 alloy. (See page 18.)

remained for two centuries. In 1816, on the adoption of gold as the only standard in the reign of George III, silver became a purely token coinage, and the pound troy of sterling silver was made to yield 66 shillings.

The weights of the individual coins (those of cupro-nickel also) remain unchanged at the present day and are derived from the pound troy in the way described above. It follows that in whatever way 5s. 6d. (66 pence) worth of silver coins is made up, it will always weigh 1 oz. troy or one-twelfth of a pound troy.

In 1920, when the price of silver rose to over 80 pence per ounce, and it therefore became profitable to melt down silver coins made of the 925 alloy for the sake of the silver contained in them, the fineness was reduced to 500 parts per 1,000, but the weights remained the same. In 1947 silver-containing coins began to be disused, even as a token coinage, and their place was taken by base cupro-nickel coins. This was done on economic grounds and was an outcome of the Lease-Lend agreement made with the United States during the war.

It will therefore be seen that the steps which led to the selection of particular alloys for coinage purposes were not dependent solely on a knowledge of their metallurgical suitability but depended also upon the political or economic exigencies of the times. These factors are still very powerful.

In the middle of the nineteenth century a serious attempt was made to bring about uniformity of both fineness and weight among national coinages. Until then, while the troy system operated in Britain, other systems were in use on the Continent. This provided opportunities for the coinage of one country to find its way into adjoining countries where it had from time to time a greater intrinsic value. Similar difficulties have arisen in recent times within the British Empire. At one time British coins circulated in Rhodesia while the Union of South Africa was still on the gold standard, and coins were smuggled over the border, where their exchange value was higher. In this way the supplies in Rhodesia were so depleted that an entirely new coinage had to be provided.

The Convention of 1865, known as the Latin Monetary Union, was the first serious step towards standardization in Europe. It unified the coinages of France, Belgium, Italy, and Switzerland, the standard for gold being 900 and those for silver either 900 or 835 parts per 1,000, according to the particular country.

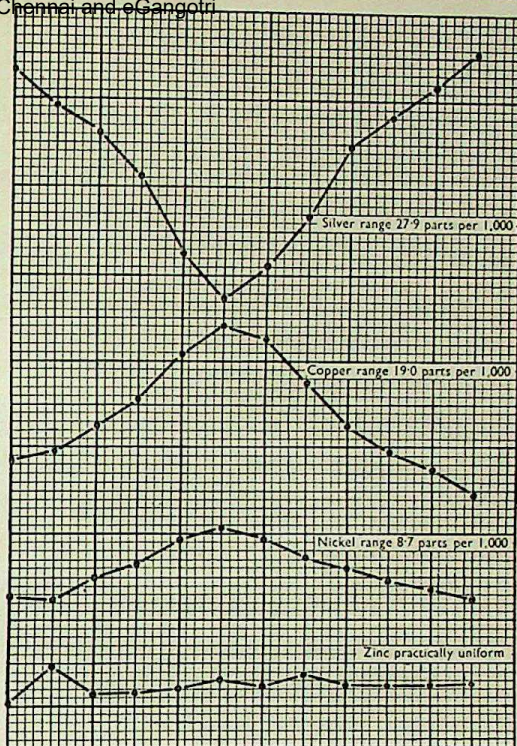


FIGURE 2 - Variations in the percentages of individual constituents of a quaternary alloy of silver, copper, nickel, and zinc across a rolled fillet of width 2.375 in. (Smith).

It is a fortunate fact that silver and copper can be alloyed in almost any proportion to give material suitable for the production of coins. Within recent years even the eutectic (i.e. mixture of the lowest melting-point) containing 72.8 per cent. of silver has successfully been used for coinage, despite its known tendency towards intercrystalline cracking. Since 1921, when the fineness was reduced from 925 to 500 parts per 1,000 in Britain, a third and fourth metal have been added in order to procure a pleasing whiteness, comparable to that of the standard which had been in existence for so long.

In general, the following properties of coinage alloys are desirable. For minting purposes the alloy should have good casting properties, giving sound bars with good surfaces; it should be ductile to ensure easy rolling, uniform in composition, and able to flow when struck between dies. For purposes of circulation the alloys should be durable, sonorous when rung, difficult to counterfeit, resistant to tarnishing, and pleasing in appearance.

It is above all desirable that through the years, whether the composition remains constant or not,

coins should not vary to any great extent in colour and general wearing properties. This condition having been satisfied, it is also desirable that, as William Morris once wrote, 'the workmanship should be good in order that people may have pleasure in things they must perforce use.'

The reduction in fineness to 500 parts per 1,000, decreed by the British Parliament in 1920, presented one of the greatest metallurgical problems in coining since the time of Edward VI, when ideals other than profit-making were probably not so much sought after, and the appearance of the coin was not so important as the swelling of the exchequer.

The introduction of the 500 alloy in 1921 drew attention to a property in alloys which is particularly prominent in those containing silver, namely liquation (i.e. partial liquefaction on heating) and inverse segregation. This phenomenon occurs also in certain types of bronzes.

In the case of copper-silver alloys (other than the eutectic alloy) it is found that one metal or the other becomes more highly concentrated near the outer surface of the bar than at the centre. The metal which segregates in this way is always the one whose addition would lower the freezing-point of the alloy. The eutectic alloy is constant in composition across the section of bar. Alloys containing more than the eutectic proportion of silver (72.8 per cent.) exhibit a concentration of copper on the outside and of silver towards the centre. In those containing less than 72.8 per cent. of silver the reverse is the case. It was into this latter class that the 1921 alloy fell, the variation in fineness between the outside and the middle of a bar 2½ in. wide being as much as 2-3 per cent. under ordinary manufacturing conditions (figure 1). This circumstance had several important effects. It meant that the only method of obtaining a correct sample of coinage bars was to take a sample from the molten metal and to granulate it in cold water, so that complete granulations could be used in the assay. Cuts from the cast bars could not be relied upon as being accurate, though

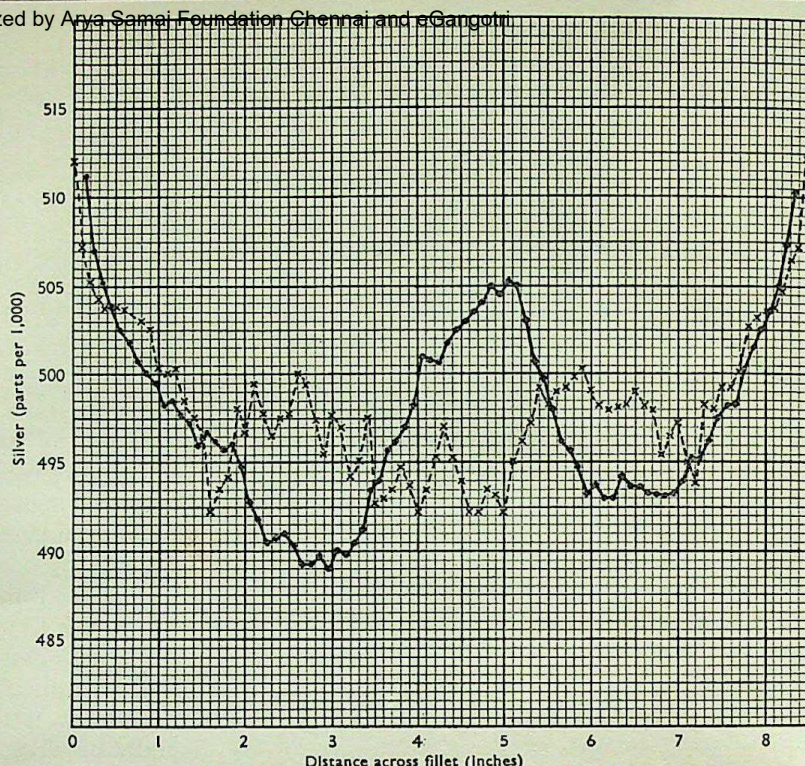


FIGURE 3 - Liquation phenomena depend to a considerable extent upon the size of the ingot. The diagram above shows how the percentage of silver varies in a fillet prepared from a 12 in. by 2 in. ingot. The alloy used contained 500 parts of silver, 400 parts of copper, 50 parts of nickel, and 50 parts of zinc per 1,000 parts of alloy. The heavy curve corresponds to the middle of the fillet, the broken curve to a line 8 in. below the top of the fillet.

an approximation could be obtained by clipping a portion on the centre-line of the blanks. Segregation made it undesirable to melt the alloy in very large units or cast it into very large bars, as control was then lost of the segregation effects and their influence on the resulting coin could not be predicted.

Although the 925 alloy exhibited a certain degree of concentration of silver along the middle of the bar, the effect was not so pronounced as the reverse one with the 500 alloy. With the 925 alloy it was possible, by careful work, to keep the fineness of individual coins within the limits of ± 4 parts per 1,000 laid down in the Coinage Act. In the case of the 500 alloy these narrow limits could not, however, be maintained, and they were expanded to ± 5 per 1,000 on 12 oz. troy of coins.

The sampling of the finished coins, cut from fillets in two staggered rows, presented difficulties on the same grounds, since some portions of the individual pieces were cut from areas rich in silver and some from areas which were poor in

silver. Theoretically, centre punches approximately of the size needed for the assay should give comparable results, provided the liquation were always regular and the punches lay consistently at a specified distance from the centre-line of the fillet. These factors cannot be guaranteed, however, in actual manufacture. Resort is therefore made to sector cuts made diametrically opposite to each other and each subtending a right angle at the centre. Mathematically it can be demonstrated that a correct assay can be obtained from any blank cut in single row along a fillet by taking three punches, regularly spaced on a concentric circle on the coin, with a radius of $0.6R$ (where R is the radius of the coin).

In order to preserve the whiteness of the coins of reduced standard an addition of 10 per cent. of nickel was made to the first series. The production of an initial surface of fine silver, to preserve the coins from tarnish during storage and the earlier stages of circulation, demanded deeper oxidation during the final annealing before stamping, and hence heavier pickling to remove the oxides thus formed. The coins containing nickel have worn well in circulation, but they presented manufacturing difficulties due principally to the mutual insolubility of silver and nickel and the consequent lack of uniformity in physical properties.

The substitution of 5 per cent. of manganese in place of nickel introduced similar production problems, and a tendency to flake was not overcome. It is interesting to note, however, that following a study of the solubility of manganese in copper and of copper in silver, an alloy was made composed of 50 per cent. silver, 8.9 per cent. manganese, and the rest copper, which showed no liquation. The strips were too hard, however, and could not readily be rolled. During the

1914-18 war American metallurgists demonstrated that, by using the purest manganese obtainable electrolytically, the rolling properties could be improved.

An alloy containing equal quantities of silver and copper had many advantages in working, but showed, of course, pronounced liquation. Moreover, the colour of the alloy is markedly pink, with the result that once the initial fine silver surface wore off in circulation the natural colour was exposed, mainly on the parts of highest relief, one of which was unfortunately the nose.

Several years of investigation resulted in the production of an alloy containing 50 per cent. silver, 40 per cent. copper, 5 per cent. nickel, and 5 per cent. zinc. The natural colour of this was pleasing, and near to that of the old alloy containing 92.5 per cent. of silver. Moreover, by ensuring that the nickel entered into the final melt in the form of a primary alloy of copper, nickel, and zinc, which protected it from the silver, no difficulties in melting and casting were encountered. The zinc, it was found, divided itself equally between the silver and the base metals. The range of liquation could be controlled and the legal limits complied with. It is interesting to note that the base metals showed individual characteristics of distribution as depicted in figure 2.

It has already been pointed out that the necessity for controlling the composition of the coinage between the narrow limits defined by law precluded the casting of large ingots, as in these the extent of liquation made control difficult. The effect of the size of ingot, and of the mass of metal generally, on the liquation phenomena is being investigated at present. An early curve obtained by E. G. V. Newman for an ingot 12 in. by 2 in. shows the complexities that are likely to be encountered (figure 3). Temperature gradients

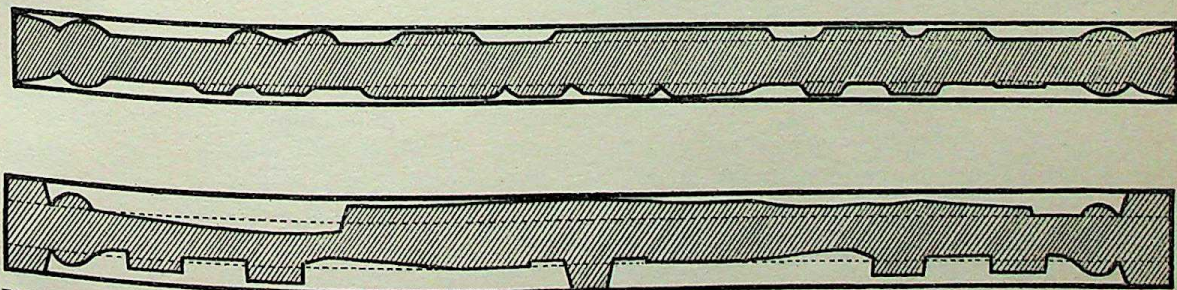


FIGURE 4 - In designing coins which are struck from the obverse and the reverse at the same time, care must be taken that peaks on one side correspond to valleys on the other, so that no part is weakened by being denuded of metal. No sharpness must be left at the bases of the various reliefs, as these might cause 'ghosts' on the other face. The upper diagram shows the section of a properly designed coin; the lower one shows various defects of the type mentioned.

within the metal and in the moulds, and the rates of casting and solidification, are among the factors obviously exerting considerable influence on the final result.

The advent of cupro-nickel alloys in place of silver alloys for the principal token coinage of Britain has removed one of the serious difficulties in coining, that of liquation, since copper and nickel are mutually soluble in all proportions. There are, however, other difficulties peculiar to the alloy. It is necessary for the casting to be done at a high temperature (about $1,400^{\circ}\text{C}$). Ingots of large cross-sectional area must be cast through pouring cups. For reasons of thermal conductivity the moulds themselves should have thicker walls than usual. Carbon absorption may occur during melting, and this renders the strip brittle. Such brittle strip can usually be reclaimed by remelting with about 0.2 per cent. cupric oxide or manganese dioxide placed in the bottom of the crucible. If the annealing is done at too high a temperature, say 800°C , the carbon in the blank may become converted into graphite. In this case the blanks are 'biscuit' brittle and must be returned for special treatment in remelting.

The colour of cupro-nickel is initially white, but it tends to become yellowish owing to slight oxidation of the excess copper. This effect is accentuated in hot, damp climates, but has been found to be not so pronounced where circulation is reasonably continuous in temperate conditions.

In most of the essential details the operations of coining are similar to those employed in other industries using non-ferrous metals. Particular attention has, however, to be paid to the preparation of the dies, since the finished pieces have not only to satisfy legal enactments as to weight and composition but also have to be identical in relief and design. It is necessary to reveal the full designs on both obverse and reverse, to portray accurately the essential distinguishing characteristics, and to please—in some measure—the aesthetic sense. The first two conditions are the care of the coiner, the last two that of the artist or designer.

The design of a model for coinage, and also for the making of medals, requires in the artist as well as in the manufacturer an intimate knowledge of the general physical properties of metals and alloys, and especially those of the alloy to be used with the particular dies. In the striking of both the obverse and the reverse at the same time there is an appreciable flow of metal on both faces, from parts of low relief to those of high relief. The

designer must take account of this, and so arrange the peaks and the valleys of the two sides that in striking the coin no portion is left denuded of metal by a withdrawal into an opposing relief. He must also, at the same time, ensure that there is sufficient metal to flow into the high-spots so that the designs are uniform everywhere. No sharpness must be left at the bases of the various reliefs, as these might cause 'ghosts' on the other face. The flowing properties of selected alloys, which are related to ductility and elongation, are thus of paramount importance. Figure 4 shows typical examples of such flow and counter-flow.

Artists normally work in one of two media. They may cut an incuse design direct into a piece of softened die steel; this was the method employed by the old master die-sinkers, of whom unfortunately only a few representatives remain. Alternatively, they may make a model in plaster, from which a relief model is made in nickel backed by copper, both deposited electrolytically; the model is very often faced by a hard, thin deposit of chromium. This model is then placed on a reducing machine, the tool of which rotates at high speed. An exact replica of the model, of the correct size of the coin to be struck, is cut by the machine in a piece of softened die steel containing 1 per cent. of carbon. Incuse matrices are produced from this punch, after hardening, by forcing it into a second die blank by means of a succession of blows.

For many years a vigorous controversy has existed between the schools favouring these two methods. The hand craftsmen contend, with some justification, that modern mechanical aids do not give the same finish or yield the same artistry as the slower manual die-sinking of the past. They believe that the feeling of the artist is not transmitted to the final piece, and that there is a consequent loss of the delicacy that characterized the work of the old masters. On the other hand, the need for rapid mass-production of exactly similar dies has demanded some assistance from an accurate machine, and to such help the modern artist is obliged to turn.

In the production of medals for limited circulation the craftsman has more opportunity of expressing himself. The reliefs are greater, and the treatment is more individual. Even here, however, the reducing machine has entered the field because of its adaptability, and because most modern artists have been schooled in relief and not in incuse designing.

The high-intensity flash-discharge tube

J. N. ALDINGTON

077819

The fact that the discharge of electricity through a gas may be accompanied by the emission of light has been well known for many years. Only recently, however, has the discharge been applied for obtaining intense flashes of very short duration. By means of such flashes it is possible to examine, both visually and photographically, a wide variety of transient phenomena. Particularly useful in this respect has been the discovery that by using mixtures of gases, such as neon and krypton, practically white illumination can be obtained.

The discharge of electricity through a gas is generally accompanied by the emission of light. For a given quantity of electricity the intensity of the light is inversely related to the duration of the discharge; if the duration is sufficiently short, the light intensity may be very high. The lightning flash is a vivid example of this phenomenon. It occurs when the electrical charge on a cloud reaches a potential sufficient to ionize the atmosphere between the cloud and earth or between two cloud masses. Circuits and tubes have now been devised which enable controlled pulses of light of very high intensity to be produced by processes not unlike those that occur in nature.

In the laboratory arrangements the electrical energy is generally provided from a capacitor charged to a high voltage, and the light is emitted from a special type of discharge tube connected directly to the terminals of the capacitor. When a voltage high enough to ionize the gas is applied to the triggering electrode of the tube, the consequent sudden and almost complete discharge of the capacitor results in the production of a vivid flash. Of the many gases or metallic vapours which may be used it is of interest to note that the elements krypton and xenon, which occur in such low concentrations in the atmosphere, are among the most suitable for both visual and photographic work. By their use it is possible to obtain luminous efficiencies exceeding 50 l/W

(lumens per watt) with a light resembling daylight. The output of a single flash may have a value of the order of 10^5 lumen-seconds, enduring for a few microseconds or extending over a period of several hundred microseconds.

It is this combination of extremely short duration and high efficiency which makes the new flash-discharge lamp such a valuable tool for both visual and photographic investigations. In its simplest form it consists of a glass or quartz tube filled with a suitable gas at a pressure which may lie between that of a few millimetres of mercury and one or more atmospheres. Electrodes are sealed into the ends of the tube, and the voltage which must be applied to them to cause an electric discharge to pass is called the ignition voltage of the device. When a lamp of this type is connected to the terminals of a capacitor charged to a voltage of the order of 75 per cent. of the ignition voltage, little or no current will flow. When, however, the gas within the tube is ionized by the application of a high voltage

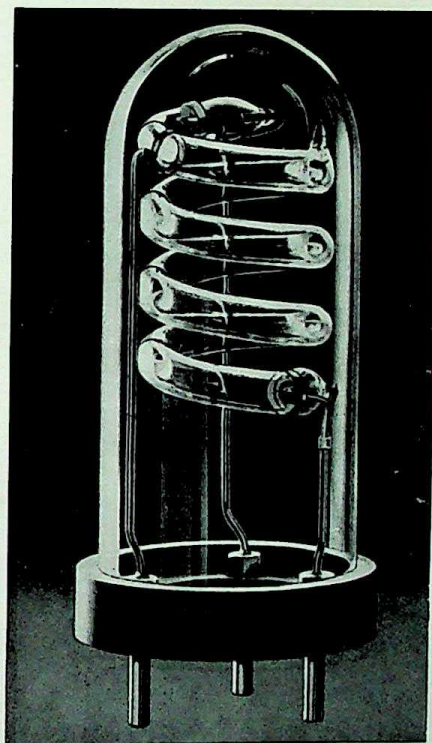
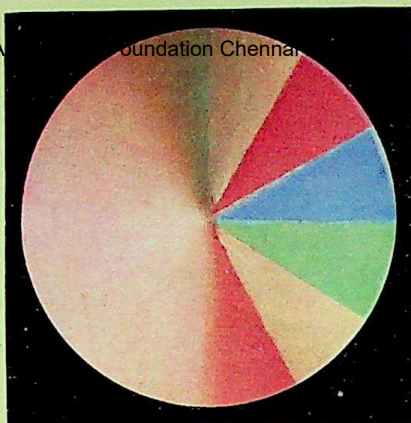
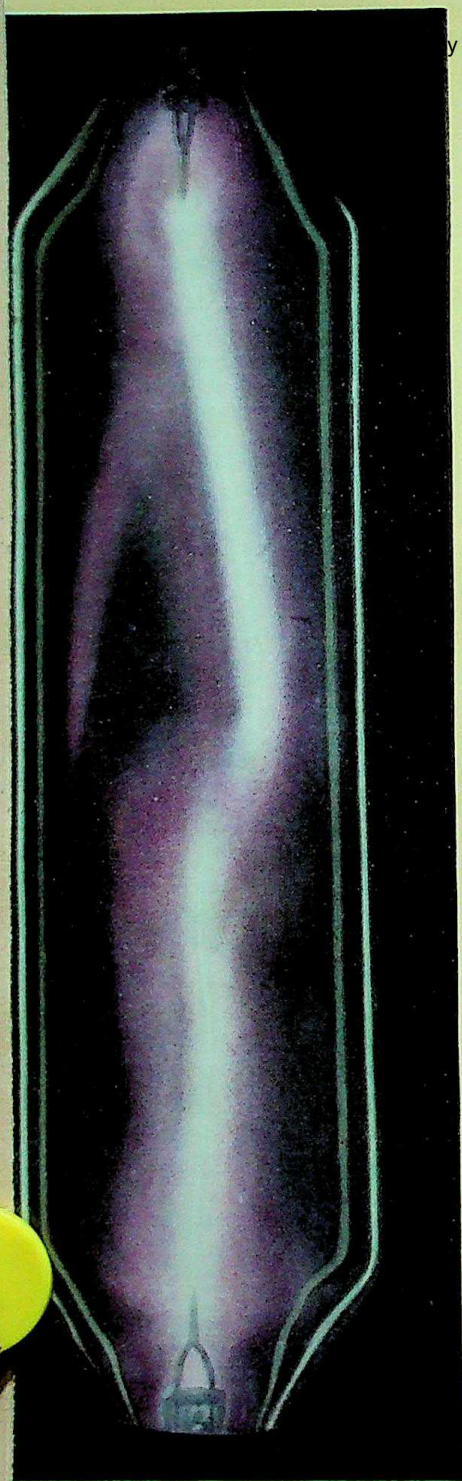


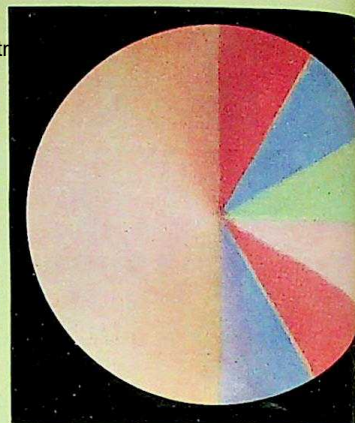
FIGURE 1 - High-intensity flash-discharge tube capable of discharging 400 joules.

to a wire wrapped round the tube or to a trigger electrode sealed in it, the capacitor will immediately discharge through the gas with the production of a powerful flash of light. The intensity, colour, and duration of the flash depend among other things on the following factors:

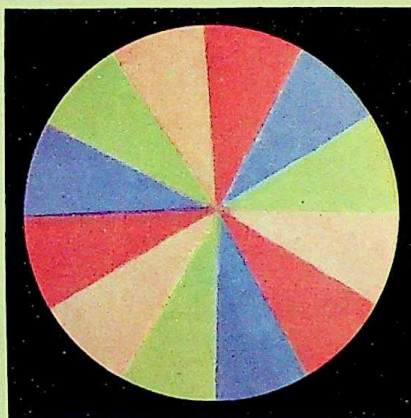
1. The energy of the discharge.
2. The nature of the electrodes.



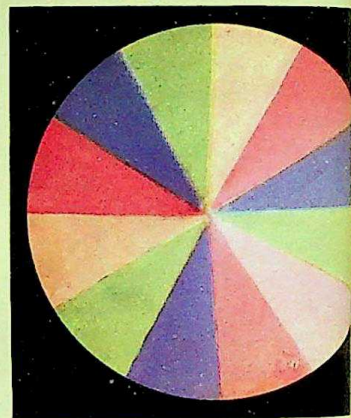
(a)



(b)



(c)



(d)

FIGURE 2 (above)

- (a) Coloured paper cone revolving at 3,000 revolutions per minute, illuminated from one side by a tungsten-filament lamp and from the other side by a train of synchronized flashes of light occurring at the rate of 3,000 per minute.
- (b) Repetition of (a), showing phase-shift of cone in respect to the flashing light source.
- (c) Stationary cone photographed by the light from a 'daylight' fluorescent lamp.
- (d) Stationary cone photographed by the light from a tungsten-filament lamp.

FIGURE 3 (left) - Flash discharge through a mixture of argon and neon.

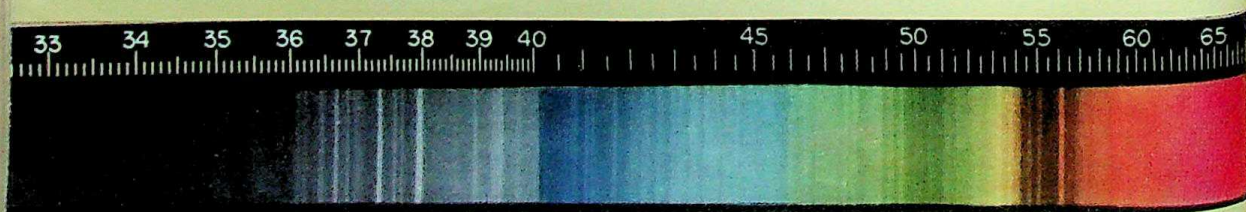


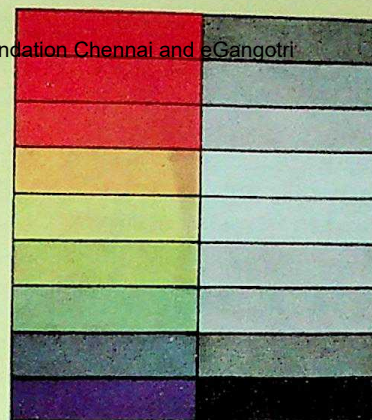
FIGURE 4 - Spectrum of the light from a krypton/xenon flash tube operated at 5,000 amperes/cm.².
CC-0. In Public Domain. Gurukul Kangri Collection, Haridwar



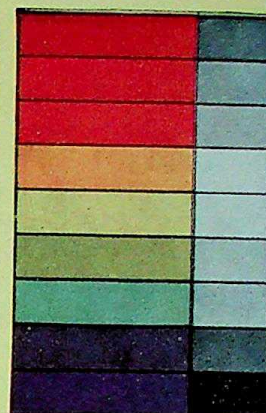
FIGURE 5 - Photograph of a coloured ball held up in a jet of water. Note resolution of the water jet into single droplets by a flash lasting for about 25 microseconds.

FIGURE 6 (right) - Photograph of Ilford colour-test chart with various sources of illumination.

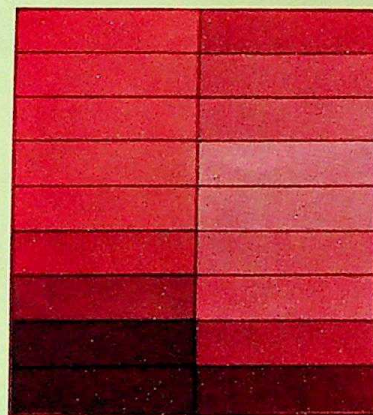
- (a) Daylight.
- (b) Krypton flash lamp.
- (c) Neon flash lamp.
- (d) Krypton-neon flash lamp.



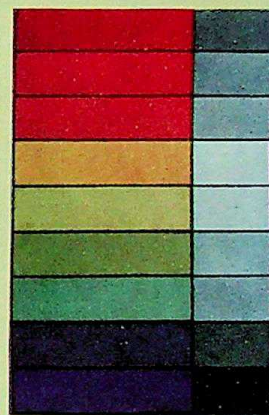
(a)



(b)



(c)



(d)

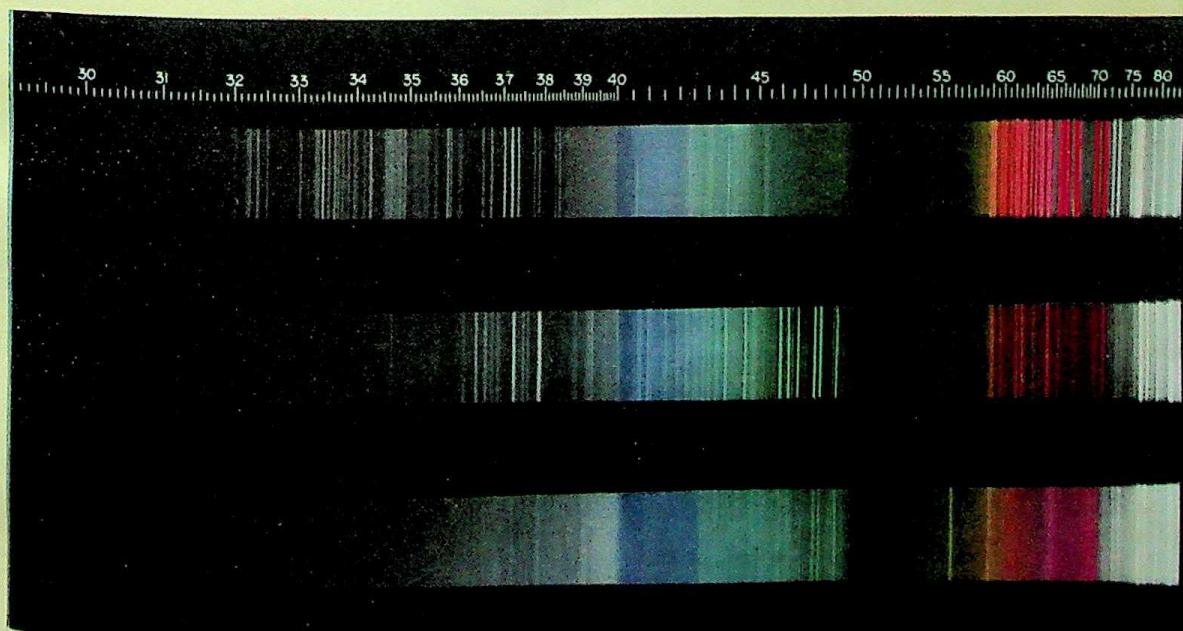


FIGURE 7 - Spectra of three flash-discharge lamps: (a) Neon filling, (b) Krypton-neon filling, (c) Krypton filling. CC-0. In Public Domain. Gurukul Kangri Collection, Haridwar

3. The dimensions of the tube.
4. The nature and pressure of the gas contained in the tube.

Lamps have been produced in Britain capable of dissipating 8,000 joules in 400 microseconds, corresponding to an average power over the discharge period of 2×10^7 W. The maximum light output during the discharge pulse may reach values greater than 10^9 lumens, with a brightness greater than 10^6 candles/cm.². This is several times the brightness of the sun's disk as viewed from the earth.

The nature and uses of this type of lamp can be illustrated by a short account of some experimental results. Figure 3 shows the effect of discharging the energy from a 10 microfarad (μ F) capacitor charged to 3,000 V through a mixture of neon and argon at a pressure of 50 mm. of mercury. The discharge was passed between tungsten electrodes, 10 in. apart, contained within a glass tube 4 in. in diameter. The visible path of the discharge was coloured and of uncontrolled form, and its position varied with each discharge pulse. A controlled path can, however, be readily attained by confining the arc within glass or quartz tubing of relatively narrow bore properly related to the current in the discharge itself. It has been indicated in an earlier section that in order to obtain a considerable light output the lamp must be made capable of handling power which has an instantaneously high value. The way this result has been achieved in practice will be understood by reference to figure 1, which shows a typical lamp capable of dissipating 400 joules in a single flash. Noteworthy features of the design are the length of the discharge path,

by winding the containing tube into a spiral form, and the size of the electrodes, which are very small considering the high-order currents which flow during the period of peak discharge. The discharge tube itself and the connections to it are protected by an outer domed cover. The main and the triggering electrode contacts are kept

as widely separated as possible on the base because of the high voltages which are used. In the case illustrated the triggering electrode consists of a narrow strip of metal wrapped round the outside of the various convolutions of the spiral.

The energy of a charged capacitor is given by the expression

$$E = \frac{1}{2} CV^2,$$

where C = capacitance and V = voltage.

It follows that for a given amount of energy to be discharged it is advantageous to use as high a voltage as possible, since E varies as V^2 . This permits a smaller capacitor to be used, with a corresponding reduction in the duration of the flash. The use of higher voltages requires the provision of a longer discharge path or a higher gas pressure, so that the striking voltage of the device will always be higher than the voltage to which the capacitor is charged.

The electrical circuit required for the effective operation of these high-intensity flash-discharge lamps is quite simple in principle. The capacitor is charged from a high-voltage direct current supply, such as that provided by a transformer and rectifier. It is always necessary to arrange the circuit so that the capacitor becomes fully recharged in an interval of time materially less than the desired interval between successive flashes of light. The actual instant at which a



FIGURE 8 - Photograph, showing contents of a beaker of water flung vigorously upwards, taken with the flash, from a krypton lamp, lasting 100 microseconds. Note the elliptical shape of some of the water droplets, with the long axis in the direction of motion.

given flash occurs is determined by a triggering pulse, which is applied synchronously with the phenomenon which it is desired to photograph or observe. A voltage sufficient to produce a spark about 1.5 cm. in length in air is generally sufficient for this pulse, which may be provided by an induction coil with its primary circuit actuated by the light, or sound, or movement associated with the phenomena to be observed. Means are therefore available for producing isolated flashes of light of sufficient intensity to secure sharp photographs of objects moving at high speeds. Alternatively, to meet the case where it is desired to carry out the visual examination of a rapidly recurring cyclic or periodic motion, circuits have been devised to yield a series of flashes at frequencies which may be varied from one or two per second up to one thousand per second, or even higher. A circuit of this type will also enable a continuous train of light flashes to be produced, each occurring synchronously with the movement of a piece of machinery, thereby providing an illusion of arrested motion. Light-source stroboscopes have of course been known for many years, but in general their light output was very low, making them suitable for use only in a darkened or dimly lit room. With the high-intensity flash tube, however, a stroboscopic illuminator can be produced which not only gives sufficient light to enable moving machinery to be examined with ease under conditions of normal illumination, but renders objects in approximately their natural colours. This important result is achieved when krypton or xenon, or a mixture of these gases, is used in the flash lamp and the current density in the tube is sufficiently high. The spectrum shown in figure 4 was taken with a typical high-voltage lamp operating at about 5,000 amperes/cm.².

It will be seen that the spectrum of a krypton-xenon mixture under these conditions is particularly favourable for both visual and photographic work. As the spectrum in the visible region is well filled over the whole range from 4,000 to 7,000 Å, the quality of the light can be suitably modified by means of filters if it is desired to take photographs in colour.

Several of these aspects are illustrated in figures 2a and 2b, which show a shallow cone, rotating at 3,000 revolutions per minute, illuminated from one side by the light from an incandescent tungsten lamp and from the other side by a train of synchronized flashes of light occurring at a frequency of 50 per second. Both the colour

effects and the sharpness of the illusion of arrested motion on the right-hand side of the cone are brought out in the illustration. The mixing of the colours to produce an appearance of amber, due to persistence of vision, is clearly shown on the left-hand side of the cone illuminated by the light from the incandescent lamp. The two additional views (figures 2c and 2d) were taken with the cone stationary under the illumination from a 'day-light' fluorescent lamp and from a gas-filled tungsten-filament lamp respectively.

In the course of developing these high-intensity flash sources it became apparent that the possibility existed of simultaneously exciting the individual spectra of mixed gases or metallic vapours. In particular, in view of the predominance of red radiation in the neon spectrum and the somewhat blue light of the krypton discharge at high current density, investigations were carried out to determine to what extent control could be exercised over the colour and colour-rendering properties of the light from a lamp containing a mixture of these elements. The spectra illustrated in figure 7 indicate some of the possibilities. The illumination of the spectrographic slit was obtained by flashes of light from three high-intensity experimental discharge lamps filled respectively with pure neon (figure 7a), a mixture of neon and krypton (figure 7b), and pure krypton (figure 7c). It will be seen from the middle spectrogram that neon and krypton can be simultaneously excited under the conditions which obtain in these flash-discharge lamps. This result may be of importance in connection with the development of flash-discharge lamps for accurate colour-reproduction at high speed. The apparent lack of radiation in the region 5,000–5,500 Å is due to the low response of the photographic emulsion in this region. The table on page 26 shows the trichromatic co-ordinates¹ of the light from the three experimental lamps compared with the co-ordinates of an incandescent radiator at 6,500° K.

The colour photographs of an Ilford test chart reproduced in figure 6 illustrate the suitability of these new flash-discharge lamps for high-speed colour photography. Except in the case of figure 6a, where the illuminant was daylight, the photographs were taken with a single flash, lasting for about 100 microseconds, from each of the three special lamps mentioned above. It will

¹These co-ordinates or coefficients measure the contribution made to the whole colour by the primary red, green, and blue components.

Digitized by Arya Samaj Foundation Chennai and eGangotri

Light Source	Trichromatic Co-ordinates		
	x	y	z
1. Incandescent indicator at 6,500° K.. ..	0.310	0.316	0.374
2. Neon flash lamp	0.580	0.355	0.065
3. Krypton-neon flash lamp	0.320	0.315	0.365
4. Krypton flash lamp ..	0.310	0.310	0.380

of ion tracks in Wilson cloud chambers. Elucidation of the factors influencing atomization of liquid fuels at injector jets is being facilitated by the use of the powerful light pulses from special flash tubes. High-speed photography on continuous-film cameras has become possible, and picture repetition rates of 1,000/sec. are feasible.

Flash-discharge lamps are used in a special photographic zenith tube, now under construction for the Royal Observatory, Greenwich, for the determination of time with high accuracy. The lamp, which is flashed by impulses from one of the standard quartz crystal clocks, illuminates a slit attached to the moving carriage carrying the photographic plate on which the star images are recorded. The image of the slit is focused on a stationary photographic timing plate, across which a number of images are produced. The instrument thus incorporates a high-precision chronograph and, at the same time, a check on the uniformity of motion of the plate carriage is provided.

be seen that both in the case of the krypton lamp and in that of the krypton-neon lamp the colour-rendering properties of the light as reproduced by Dufaycolour are reasonably close to those of daylight.

The evolution of the high-intensity flash-discharge lamp has enabled improved techniques to be devised for the visual inspection or photographic recording of many different types of transient phenomena. For example, linear forms of lamp have proved of value in the photography

Max Planck (1858-1947)

On 4th October there died at the age of 89 Max Planck, whom we may properly term venerable for his age, for his achievements, and for the admiration and respect in which he was universally held. As long as science is cultivated he will be honoured as the originator of the quantum theory, to which his claims are undisputed. The enunciation of the quantum principle was not one of those advances where there was a race, in which the actually accepted discoverer arrived a little before his competitors. The discovery was made by Planck alone, in a sense before its time; it caused no sensation, and its significance was realized comparatively slowly. It was the careful, critical, continued examination of the basis of the thermodynamics of radiation that led Planck to the quantum hypothesis, and Einstein, Debye, Born, Bohr, and other great names later showed how wide and how fundamental was its scope. Today it can be said to dominate the field of theoretical physics and to extend beyond that region.

It was Planck's work that brought into prominence the fundamental duality in the theory of radiation, namely the particle aspect and the wave aspect, which have been reconciled only of recent years. It is Planck's work that ultimately underlies all theories of atomic change, nuclear

and extranuclear. Another direct consequence of his great discovery is the uncertainty principle, which has disturbed the basis of physical science. It is strange to think that all this sprang from a difficulty in the theory of the distribution of energy in the spectrum of the light from a full radiator.

Max Planck was already well established as a theoretical physicist, and had been many years professor in the University of Berlin, when he first put forward the quantum theory. The many high honours which accrued to him, when the scope of his discovery was realized, included a Nobel Prize in 1919, when he was over 60, and the Copley Medal of the Royal Society ten years later. His simple, upright, modest, yet critical character was unchanged by the world-wide recognition of the importance of his work. The last thirty years of his life were saddened by many family misfortunes and by the political events in his fatherland, which were repugnant to him. Accompanied by his wife, who survives him, he visited England in 1946 for the Newton celebrations and, though feeble in body, showed his accustomed clarity of mind. With him passes one of the great creative figures of modern physics.

E. N. DA C. ANDRADE

Parasitic animals and the world's food

Digitized by Arya Samaj Foundation Chennai and eGangotri

G. LAPAGE

At the present time, when the world is suffering from a general shortage of food, steps have to be taken not only to increase production but to prevent loss and wastage. One of the chief menaces is the parasitic animal, various species of which are responsible for the annual loss of food to the value of hundreds of millions of pounds. In the present article Dr Lapage surveys the problem, explains its gravity, and emphasizes the need for international co-operation.

There is no need at the present moment to stress the difficulties which impede the supply of an adequate diet to the nations of the world. The conservation and increase of supplies of food, their distribution, the regulation of their consumption by the various peoples, the prevention of waste, and a number of other problems, are engaging the urgent attention of experts all over the world. Much has been written about these problems, but comparatively little—or, some would say, all too little—is told to the public about the losses inflicted upon our food supplies by living things which prey upon them in one way or another, whether these be animals which consume them as food, or bacteria, viruses, or parasitic animals and plants which cause disease. These losses are suffered, first, by our crops and, second, by our domesticated animals, which provide us with meat, milk, eggs, and other products.

It is always difficult to assess this damage with accuracy. Probably we shall never know the precise extent of the injury done to crops by living things which either directly consume them or produce disease in them. Estimates of the damage done to domesticated animals by bacteria, viruses, and parasitic animals have, however, been made. Although this article is concerned chiefly with the losses inflicted upon our food supplies by parasitic animals only, it is helpful at the outset to gain some idea of the total losses inflicted by all kinds of disease.

Two estimates, one of the total losses incurred in Britain and the other of those in the United States, will give us in financial terms a measure of the order of the injury inflicted by the combined activities of bacteria, viruses, and parasitic animals. The Second Report of the Committee on Veterinary Education in Great Britain [1], published in 1944, states that the annual loss in England and Wales, due to diseases of farm livestock alone, is 10 per cent. of the output

of the meat, poultry, and dairy industries, and represents a loss of nineteen million pounds a year. The National Veterinary Medical Association of Great Britain and Ireland [1] later showed that this estimate was too low, and added evidence that four of the major diseases of cattle alone caused an annual loss of twenty million pounds, of which twelve millions were ascribed to the loss of milk and the remainder to loss of stock. With these statements we may compare the estimate of the United States Bureau of Animal Industry [3], issued in 1942, that the total loss on domesticated animals in the United States through all the diseases listed in the estimate was 418 million dollars a year. W. A. Hagan, a distinguished American veterinary expert, has expressed the opinion [2] that this figure is far too low and should be increased to at least 1,000 million dollars.

Hagan and others have further pointed out that diseases of farm animals affect our food supplies, not only by killing the animals but by retarding their growth and reducing their production of milk and eggs. They may also injure their breeding capacity and render them liable to further diseases. Sick animals require special care and feeding and may cause considerable loss of food materials which might otherwise be converted into meat, milk, and eggs, or diverted to human use. This wastage is by no means negligible. Experiments in the United States, for instance, have shown that whereas 3.1 lb. of feed will produce in 7 weeks a weight increase of 1 lb. in chickens protected from parasites, 4.5 lb. of feed are required to produce a weight increase of 1 lb. in infested chickens. Experiments on sheep and cattle in Britain, the United States, and elsewhere show that the same general conclusion applies to these animals also. There can be no doubt that persistent unthriftiness, differentiated from actual disease or death, is one of the major

causes of the serious loss of food supplies indicated by the figures quoted above. And these, be it noted, are figures of the losses inflicted upon food supplies derived from domesticated animals only. If the losses inflicted upon our crops could be added to them, the total would indeed be startling.

When we inquire into the relative degrees of damage done by different diseases of farm stock it becomes very difficult, if not impossible, to assess accurately the relative importance of diseases caused by bacteria and viruses on the one hand, and those caused by parasitic animals on the other. In one country the former may be the more important, in another country the latter; and unpredictable factors, such as local epidemics, may upset the normal state of things. The estimate mentioned above [3], issued by the United States Bureau of Animal Industry, ascribed an annual loss of 290 million dollars to the various parasitic animals included in that estimate, a figure which is 69 per cent. of the total loss caused by all the diseases considered. In some other countries the relative losses inflicted by these two classes of injurious organisms might well be reversed, but in all parts of the world, and especially in the warmer countries, parasitic animals are responsible for a great deal of the damage. It is, in fact, never easy to assess the relative importance of the bacteria and viruses and the parasitic animals. One reason for this difficulty is that parasitic animals may seriously affect the health of domesticated stock without causing actual disease; the health of the stock may, however, be reduced by them to such an extent that their resistance to diseases caused by bacteria and viruses is lowered, perhaps fatally. Conversely, bacteria and viruses may affect the vitality of animals so seriously that they contract heavy infestations with various other parasites which still further damage their health.

Let us now transfer our attention more particularly to the various kinds of parasitic animals which menace the world's food supplies. Briefly we may say that they belong to four of the main divisions into which the zoologist classifies the animal kingdom. These divisions are:

1. The Protozoa, single-celled animals of which an example is the malarial parasite of man.
2. The Flukes (Trematoda) and Tapeworms (Cestoda).
3. The Roundworms (Nematoda), a group which includes (a) the eelworms and their relatives, which attack potato, sugar beet, wheat, oats, barley, rye, and other edible crops as well as

- many plants of horticultural value, and (b) several species injurious to farm livestock.
4. The Insects, Ticks, and Mites, and some of their relatives.

To these in localized areas, and especially in the warmer countries, we may add some kinds of leeches and the few species of blood-sucking bats.

Some estimates of the losses inflicted by particular species of these parasitic animals will reveal the extent of their threat to our food supplies and the saving of essential foods which might result if their attacks could be effectively controlled.

The annual losses caused by various species of protozoa in the United States have been estimated at ten million dollars [3], and half of these losses have been ascribed to the disease of poultry called coccidiosis. This disease is caused by protozoa belonging to a group called the coccidia, one species of which (*Eimeria tenella*) may be so harmful that it has been estimated [8] to kill 12-20 per cent. of all the chicks hatched in the United States. Other species of coccidia attack other domesticated birds and also cattle and sheep, being especially harmful to calves and lambs. Among the protozoa are also the trypanosomes, some species of which cause the diseases called nagana of cattle and surra and dourine of horses; the organisms which cause histomoniasis of turkeys and trichomoniasis of cattle; the species of the genus *Babesia* which cause redwater fever and Texas fever of cattle; and the relatives of the genus *Babesia* which cause the deadly East Coast fever of cattle in Africa (theileriasis) and anaplasmosis. An estimate [3] of the losses due to anaplasmosis in the United States is \$100,000 a year, and one severe outbreak of this disease in Kansas in 1944 caused a loss of \$2,500,000 as a result of the deaths of the cattle affected [8]. This latter estimate is a good example of the great increase in the losses sustained which may occur when, for any local or other reason, a disease assumes epidemic proportions.

The flukes and tapeworms are responsible for extensive losses of meat and other foods provided by animals, the liver fluke being especially harmful in this way. It attacks the livers of cattle and sheep and may either kill the animal or affect its health so severely that much meat and milk are lost. A statistical analysis [4] of the records of the slaughter of more than 73,000 cattle in England and Wales has shown that this parasite may cause an annual loss of liver substance costing, at retail prices, £200,000. To this must be added the loss of liver extracts for medicinal purposes and the

high, but not easily assessed, reduction of meat and milk. There is little doubt also that the liver fluke may also cause appreciable deterioration of the capacity to produce calves and lambs.

In the United States the losses caused by the liver fluke are proportionately higher. During the eleven years between 1933 and 1943 the livers of 1,400,000 cattle and 60,500 calves were condemned because they were infected with liver fluke, and it was estimated [7] that 1,075,000 lb. of liver were lost annually during this period. The annual loss in live weight of cattle and calves was estimated at about 2,733,000 lb., which amounts to about 1,366,000 lb. dressed weight. The annual loss of food in terms of liver and beef was stated to be 1,220 tons. The milk secretion was lowered by 16 per cent. by heavy infestations with liver fluke, and the breeding activities of the animals were also reduced. This estimate may be compared with the statement made by the United States Bureau of Animal Industry [3] that the annual loss caused by liver fluke and tapeworm in the United States amounted to five million dollars. It is known that in some areas of the United States 50 per cent. of animals' livers have to be condemned because they are infested with liver fluke [5], and this figure may be at times equalled or even exceeded in slaughter-houses in some parts of Britain. We have to remember, of course, that liver fluke disease depends for its distribution upon certain species of aquatic snails, and that its incidence is therefore controlled to a considerable degree by the nature of the country and by climatic conditions. It is a disease especially of damp areas, and this is one of the reasons why it is most prevalent in Britain in north-west England and North Wales. It is, however, also common in South Wales and south-west England, while the areas most free from it are the southern and south-eastern counties. In some parts of Eire its incidence would seem to be even higher than it is in England and Wales.

The group of roundworms includes some of the most damaging pests of food-producing animals, and hardly any country in the world escapes the serious losses which they can inflict. In this group also are the eelworms and their relatives, which do such extensive harm to many of man's essential crops. In Britain the full extent of the damage caused by these species is not yet known, but they certainly severely injure our crops of potato and sugar-beet in some areas. Other species of the roundworms parasitic upon plants attack wheat, oats, barley, rye, tomatoes, and other edible

plants, and the horticulturist experiences considerable losses caused by species which attack a great variety of flowering plants.

The roundworms parasitic in farm livestock belong to several species which attack various organs of the body, but probably the most harm is done by the species living in the food canal. Those in the food canals of sheep, cattle, and domesticated birds cause a form of gastro-enteritis which is one of the most serious handicaps of the livestock farmer throughout the world. The National Veterinary Medical Association of Great Britain and Ireland has estimated [10] that the gastro-enteritis caused by these roundworms in sheep alone costs Britain some £348,000 a year, a sum which is about one-third of the total cost of the ten major diseases from which British sheep suffer. To this loss must be added the losses due to the similar disease in cattle and also that caused by other species of roundworms which attack cattle or sheep or both. Among the latter species are the nodular worms which render the intestines of sheep useless for the manufacture of catgut and other products, and the hookworms which suck blood.

Many species of roundworms consume blood, but the hookworms remove especially large quantities of it. Anaemia is therefore one of the common symptoms of disease caused by the roundworms which live in the food canal. The nodular worms also unfavourably affect the condition of the animals in which they live, and it has been estimated [9] that they cause in the United States a loss of 45,000 tons of mutton annually, not to mention a further annual loss of 6 million dollars due to damage to the intestines used for the manufacture of catgut. Nodular worms may damage the livers of the animals in which they live, and thus add appreciably to the losses caused by liver flukes.

Another roundworm (*Onchocerca gibsoni*), which is sometimes called the nodular worm of cattle because it causes the formation of nodules in the skin and underlying tissues of these animals, inflicts severe losses in Australia [11]. Beef carcasses have to be mutilated by the excision of the nodules before they can be exported to Britain, and briskets may have to be removed. As many as 80 per cent. of the cattle in central and north Australia may be thus affected [6], so that the losses may be very great. They are all the more serious because this roundworm does not occur in Argentina, a country which is one of Australia's chief competitors in the beef export trade. In

addition to the species just mentioned, other kinds of roundworm do appreciable damage in various parts of the world. There are, for instance, the giant kidney worm, which attacks the kidneys of pigs, the large roundworm which lives in the intestines of these animals, and other species which live in the intestines of poultry and other domesticated birds. An idea of the overall damage inflicted by roundworms as a whole may be gathered from the estimate [3] that they are responsible, in the United States, for a total loss of 110 million dollars every year.

The large group of animals which includes the insects, ticks, mites, and their relatives may affect our food supplies in several ways. First, they may themselves consume human and animal foodstuffs. Examples of this kind of damage are so familiar that we need only mention the enormous damage inflicted by locusts, and the losses due to the many insect pests which attack our crops. Less well known is a second type of damage caused by insects, ticks, and mites which are temporarily or permanently parasitic on the exterior of the bodies of farm livestock. These species harm animals and birds in at least three ways: (1) they annoy and irritate to such a degree that the animals suffer from this cause alone; (2) their young (larval) phases may be parasitic in the internal tissues of the animals; and (3) they may transmit to the animals other kinds of parasites which cause serious diseases. Some species of them inflict more than one of these kinds of injury. The extent of the first-named kind of harm is not, perhaps, always realized. Animals and birds which are continually being bitten by blood-sucking external parasites such as mosquitoes, lice, and ticks not only lose blood and suffer from infected bites or sores produced by scratching, but are also restless and lack sufficient sleep. Consequently they do not feed normally and fail to thrive. Nor is this kind of injury inflicted only by biting and blood-sucking species. Some kinds of insects, such as the warble flies, whose larvae develop inside the bodies of cattle, do not bite their hosts, merely laying their eggs upon their hairs or skin, but the animals are thrown by their approach into a state of unrest. They may even stampede and rush wildly about, giving the impression that they are trying to avoid the flies; or they may take refuge in water and shady places, suggesting to the observer that they are aware that some species of warble flies lay their eggs only on the legs or lower parts of the body. The animals thus affected do not feed properly and therefore do not produce so much

meat or milk. Horses may be affected in a similar way by horse bot flies. It is difficult to estimate the reduction of food supplies caused in these ways, but an idea of its extent may be gathered from one estimate [3] which places the damage done in the United States by the external parasites of poultry at 85 million dollars a year.

The damage inflicted by the larval phases of insects and other arthropods upon the internal tissues of farm livestock into which they penetrate may be much more serious than that which is inflicted by external parasites. In this category we should include the mites which cause the various forms of scabies, because these mites live, not on the exterior of their hosts, but actually in the tissues of the skin. Here also we include the larvae of warble and bot flies just mentioned. The larvae of the former, after a period of life in the interior of the bodies of cattle, appear under the skin along the backbone, where their presence causes the formation of abscesses, in the pus of which the larvae live. They cut holes in the skin in order to obtain oxygen from the air, thus doing considerable damage to the hides. In addition, the meat around the abscesses is rendered unfit for human consumption. The total damage caused is therefore considerable. The United States Bureau of Animal Industry [3] assesses its cost at 65 million dollars a year, and in other countries the harm done is proportionately high. The larvae of the screw-worm flies, and those of the blowflies which attack sheep and cause the formation of sores and abscesses in the skin, also do extensive harm. Similarly the larvae of the sheep nostril and nasal flies, which burrow into the nasal sinuses and may attack the brain itself, cause heavy losses in the form of poor condition or actual death. In the United States hornflies are serious cattle pests, and the buffalo fly is spreading in Australia, where it attacks cattle.

The third form of damage inflicted by blood-sucking insects, ticks, and mites, namely the harm caused by their introduction into farm livestock of other kinds of parasitic animals, can hardly be estimated. Examples of diseases transmitted to farm livestock have been given earlier in this article. Many species of ticks are especially harmful in this way, because some of the causes of disease transmitted by them are passed from one tick generation to another. If we could get rid of the ticks and also of the insects injurious to farm livestock, the majority of which belong to the group of two-winged insects (diptera), we should

be able to eradicate many of the most serious diseases of farm animals. some of which have been specifically devised to combat the organisms which cause disease. The contributions made by the study of animal and plant nutrition are proving to be specially important in this respect. These improvements are based upon biological studies of farm animals and crop plants and of the organisms which attack them, and are among the finest fruits of the modern co-operation between the veterinarian, the physician, the biologist, the biochemist, and the biophysicist.

Throughout this article an attempt has been made to focus attention upon the parasitic animals rather than upon the bacteria and viruses which affect the food supplies of the world. If the food supplies of Britain or any other individual country had alone been considered, the picture would have differed in some details, because in some countries, and even in some areas of each country, different species of parasitic animals cause greater losses than they do elsewhere. Nowadays, however, it is the world picture of food supplies that matters most. Lack of space has prevented discussion of one important feature of it, namely the damage which may be inflicted upon foods after they have been gathered.

At first sight the picture presented is not a cheerful one, but we may take comfort from the reflection that it is a picture of one aspect only of a many-sided complex, the full consideration of which would require a volume. It has not been possible, for instance, to discuss the important implications of the fact that the study of parasitic animals and their control is still so young a branch of science that the major advances in it have been made within the last fifty years or so, many of them during the last decade. Nor has it been possible to discuss the implications of the recent discoveries of such powerful antiparasitic weapons as Gammexane, D.D.T., the sulphonamide drugs, phenothiazine, hexachloroethane, and other substances, some of which promise to give us, when we have learnt how best to apply them, a much greater measure of parasite control. Not less important, and possibly in the long run more important, are effective improvements in our methods of managing farm livestock and crops,

There is little doubt that the co-ordination of scientific effort will eventually give us all the necessary control of the menaces to our food supplies indicated in this article. From its haunts in the wilds of Brazil a species of malaria-carrying mosquito was largely eliminated, and this amazing feat was recently repeated in Egypt. Tuberculosis of cattle, imported into the United States from Europe during the nineteenth century, has now been virtually extinguished in that country, and this has been done in spite of the fact that we know of no drug which will cure this disease of man and animals. Several factors have co-operated in the accomplishment of these tremendous achievements, but not the least of them have been hard work, the co-operation of men with one another, the will to succeed, and the necessary money to put into action the measures which scientific research has indicated. If the same degree of effort, the same willing international co-operation, and the same resources of money and knowledge are applied to the biological menaces to the world's food supplies, there is little doubt that, whatever else may happen to the food of the world, it will not in the future suffer the enormous losses which now deplete it at its very sources.

REFERENCES

- [1] Second Report of the Committee on Veterinary Education in Great Britain, 1944 (H.M. Stat. Office).
- [2] HAGAN, W. A., *et al.* *Ann. New York Acad. Sci.*, 1947, 48, 351.
- [3] *Yearbook of the U.S. Dept. of Agric.*, 1942 (U.S. Govt. Printing Office).
- [4] PETERS, B. G., and CLAPHAM, P. A. *Journ. Helminthology*, 1942, 20, 115.
- [5] *Proc. 46th Ann. Meeting U.S. Livestock Sanitary Assoc.*, 1942.
- [6] NEVIN, S. M. *Bull. U.S. Army Med. Dept.* No. 81, 113-19.
- [7] OLSEN, O. W. *Liver Fluke Disease* (U.S. Dept. Agric., Bur. Animal Industry, 1944).
- [8] Report of the Administrator of Agric. Research (U.S. Dept. Agric., Agricultural Administration, 1944).
- [9] Report of the Secretary of Agriculture, U.S.A., 1942.
- [10] Report on the Diseases of Farm Livestock (National Vet. Med. Assoc. of Gt. Brit. and Ireland Publication No. 6, 1944).
- [11] ROSS, I. C. *J. Sci. Ind. Res.*, Australia, 1927-8, 1, 233.
- [12] SARLES, M. P. Leaflet No. 228 (U.S. Dept. Agric., 1942).

Tropical fruits: their storage and transport

Digitized by Aiyaz Samad, Foundation Chennai and eGangotri

C. W. WARDLAW

Existing methods of storing and transporting tropical fruits have already made some of them abundantly and cheaply available in temperate countries. Even with more familiar fruits, however, such as bananas, grapefruit, and oranges, many problems still remain to be solved. Although the general cold storage requirements of other fruits, such as the avocado, have been ascertained by *ad hoc* experiments, comparatively little is known of the changes associated with their growth to maturity and subsequent ripening.

The Englishman who has read and heard of the many delectable fruits to be found in tropical and subtropical regions may perhaps occasionally wonder why—times of war and war's aftermath apart—so few of these exotic commodities reach his own temperate land. With bananas, grapefruit, oranges, lemons, and pineapples he is, of course, familiar; and in small quantities, at high prices, there are avocados, mangoes, limes, mangosteens, and persimmons for the connoisseur. But what of the others? All those tropical fruits with names that excite the imagination and stimulate the palate: custard apples, sweet-sops and sour-sops, papayas, durians, granadillas, guavas, jujubes, lychees, loquats, pomegranates, sapodillas, passion fruits, and a dozen others: are these only to be savoured in the mind of the reader of travellers' tales? And is he never to have a helping of yam or bread-fruit at his own table? Clearly this is a matter that deserves some consideration.

In point of fact the situation is one of some complexity, combining as it does both commercial factors—the business of growing, transporting, storing, and selling the fruit in competition with the many excellent fruits produced in temperate regions close at hand—and biological factors. It is with the latter that we are principally concerned here. In practice, any comprehensive investigation of fruit in storage involves a consideration of their physiology throughout growth, ripening, and senescence, and of the fungi and bacteria which may bring about their decay. The effective means of overseas transport is the refrigerated ship, the holds being maintained at temperatures suited to the perishable commodity being carried. For tropical fruits, investigations have been carried out in Trinidad, B.W.I. (the Low Temperature Research Station of the Imperial College of Tropical Agriculture), and in Jamaica, India, South Africa, and Australia. These researches are comparable with those undertaken

by the Department of Scientific and Industrial Research (Food Investigation Board) in Britain for temperate fruits.

SOME GENERAL CONSIDERATIONS

The major tropical fruits requiring refrigerated transport are bananas and citrus. Bananas rank as one of the most important crops throughout tropical and subtropical regions, and in some countries constitute the chief source of agricultural wealth. From small initial experimental shipments large and important export industries have developed in different parts of the world in the course of a few decades, thanks to the advance of refrigeration technique. All fruit commodities carried on refrigerated ships differ from animal commodities—beef, mutton, and game—in one important respect: they are alive. They are also, as a rule, not fully ripe or, as in the case of the banana, quite unripe. As a result they cannot be transported at very low temperatures. In point of fact it would be more exact if one described tropical fruits as being carried in *cool* storage rather than *cold* storage. Thus the Gros Michel or Jamaica banana is carried at a temperature of 53° F, mangoes at 48° F, and so on, as compared with carcasses at freezing-point or still lower temperatures.

As noted above, tropical fruits for export are harvested somewhat immature; being still alive, they require environmental conditions during storage which will permit of approximately normal though retarded maturation, so that all the appearance, flavour, texture, aroma, and other qualities for which they are prized will be preserved. If fruits are stored at too low a temperature, the ripening trend is abnormal, and various so-called 'chilling injuries,' inimical to the appearance and flavour of the fruit, result. If the storage temperature is not sufficiently low, maturation proceeds too rapidly, tropical fungal pathogens

are liable to make inroads, and extensive wastage may result.

Although the storage temperature required by a particular tropical fruit, harvested at a certain maturity, can be determined by simple trial-and-error tests, a knowledge of what is actually happening within the fruit during its slow maturation in cold storage and subsequently during ripening at higher temperatures (for the banana, 62–70° F) is less easily obtained, and sets the plant physiologist a problem of a high order of complexity. So also the pathologist has his special problems: some of the parasitic micro-organisms are present as spores on the surface of the fruit and gain access through wounds and abrasions; but others have long been present within the cells of the fruit skin as inhibited or latent infections, and renew their growth and parasitic activity only when a certain stage of maturation has been reached. In other words, as the fruit ripens the environment of the pathogen changes from one less favourable to one more favourable to its development. Studies of a far-reaching kind are thus essential.

Even a small amount of practical experience makes it clear that, if we are to understand what happens when a fruit slowly ripens in cool storage, we must also have knowledge of the antecedent developments—the formation of the fruit and its growth to the time of harvesting. Our investigations, in fact, tend to be pushed farther and farther back. Indeed, experience has taught us, both for tropical and for temperate fruits, that environmental factors (soil and climate) have a marked effect on the behaviour of fruit during cold storage and subsequent ripening and must be duly considered by the investigator. For example, grapefruit grown in dry subtropical regions can be stored without injury at temperatures below 40° F, whereas those grown under moist tropical conditions suffer chilling injuries of various kinds if kept at temperatures below 45° F. Not least, genetical characters must not

be overlooked. To take a simple case by way of illustration: whereas the Jamaica or Gros Michel banana requires a storage temperature of 53° F, the Cavendish or Canary banana can withstand rather lower temperatures, while the Lacatan—a fruit of excellent flavour and aroma—must not be subjected to temperatures below 58° F.

The maturing fruit might perhaps be described as a variable biological system, undergoing a succession of changes of a complex nature, in relation to inherent biological factors and factors in the environment. The relevant investigations will thus include observations of histological changes and studies of respiration, transpiration, and metabolic processes during growth, ripening, and senescence. At present it is not always possible to translate scientific knowledge into practice. From the commercial standpoint, the final arbiters of successful storage and ripening are the eye and the palate.

PHYSIOLOGICAL STUDIES

So far, only a very few tropical fruits—chiefly the banana and citrus fruits—have received close physiological study. Some others, including avocados, mangoes, and pineapples, have received some attention, mostly in relation to particular physiological aspects, for example, respiration, and the content of sugar and acid or oil during ripening. But tropical fruits in general still remain practically untouched by physiological investigation. This may be indicated as a field affording magnificent opportunities for research on materials as varied as they are interesting. Here an account of the best-known material—the banana—will be given, with occasional references to other tropical fruits. Broadly speaking, investigations of respiration, transpiration, and biochemical changes constitute the means by which information bearing on practical aspects can be obtained.

The fact which is probably most impressive to the layman is that the banana, intended for export from the West Indies or Central America

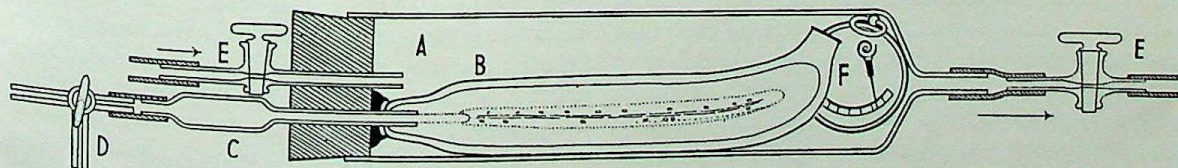
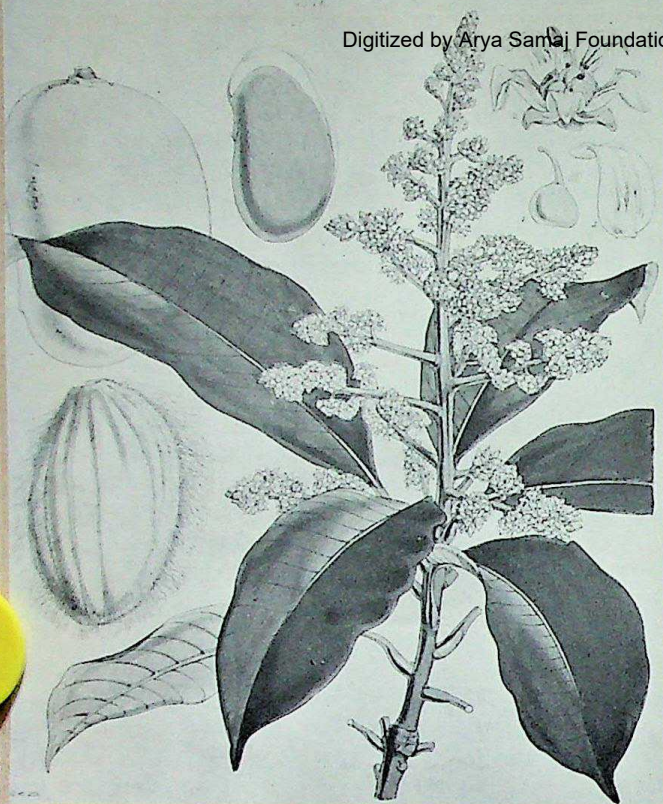


FIGURE 1—Arrangement of apparatus to permit both measurement of the respiration rate and analysis of the internal atmosphere of a banana. A, respiration chamber; B, banana in longitudinal section, showing the cavity made by the cork-borer; C, sampling tube with D, 3-way stopcock; E, 2-way stopcock; F, paper hygrometer.

FIGURE 2 - *The mango (Anacardiaceae: Mangifera indica).*FIGURE 3 - *The avocado (Lauraceae: Persea americana).*

to Europe, is harvested while still quite green and immature, at a stage described as 'three-quarters full' by the trade. As a matter of fact, such a fruit is only a little more than half-grown. Growth studies of the banana bunch, from the time of 'shooting' (i.e. the appearance of the bunch at the crown of the plant) up to the maximum size at which the bunch could be harvested for storage, show that a three-quarters full bunch is capable of a further increase in weight of approximately 50 per cent., the edible matter (the pulp) increasing by 60 per cent. Thus the later the fruit is harvested, the greater is the proportion of potential edible matter. There is the further, not unreasonable, assumption that the eating quality may also be improved. Bunches left on the plant eventually show incipient ripening, the colour of the skin changing from green to greenish yellow or yellow and the pulp becoming soft and sweetish. Such fruits are not quite ripe enough to be eaten. Before this stage is reached the weight of the bunch tends to pull over or break the fruit stalk or trunk, and insects and animals make inroads on the ripening fruits. Such fruits are almost

twice as heavy as standard fruits harvested at three-quarters full.

During the development of the individual fruits, sugar remains at a very low concentration but starch is rapidly accumulated, especially during the two or three weeks that follow the attainment of the three-quarters full stage. Respiration proceeds at a steady rate during this period. With the onset of ripening there is a marked transformation of starch into sugar and a rise in respiration rate.

Banana fruits, when selected for overseas transport in refrigerated holds at 53° F for a voyage lasting from twelve to fifteen days, are firm, green, and immature. During this period respiration proceeds at a low, steady rate and the composition of the fruit remains practically unchanged. This, indeed, is the purpose of holding fruit at a suitably low temperature—to delay the onset of maturation until after the fruit is discharged at its destination. But soon after the fruit is placed in ripening rooms at a higher temperature (62–70° F, according to the condition of bunches and marketing requirements), ripening begins.



FIGURE 4 - The papaya (*Caricaceae*: *Carica papaya*).

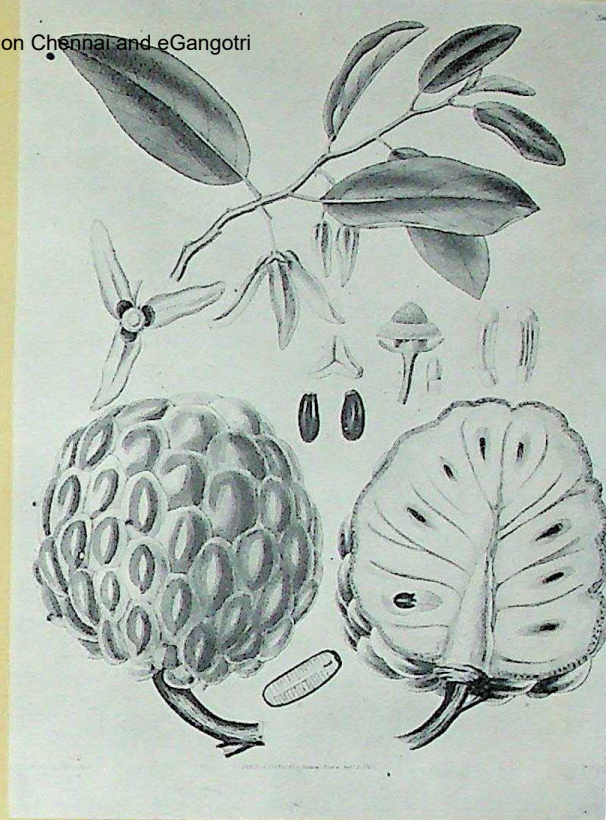


FIGURE 5 - The custard apple, sugar apple, or sweet-sop (*Annonaceae*: *Annona squamosa*).

Biochemical, respiration, and transpiration studies have shown that this is a complicated process, involving many changes which normally take place in an orderly sequence. As in other fruits, ripening in the banana proceeds from the central placental region (where the abortive seeds can be seen) through the outer pulp to the skin; it takes place a little earlier at the distal or stylar end than at the proximal or stem end.

In respiration studies, the rates of liberation of carbon dioxide and of uptake of oxygen at the fruit surface are measured as affording a useful general indication of the biochemical activities taking place within. Such studies show that the respiration rate undergoes a marked change with the onset of ripening. There is a rapid rise in the rate of utilization of oxygen and output of carbon dioxide and a rise in pulp temperature. Respiration now proceeds at the new high rate and the fruit is seen to be softening ('sprung'), colouring, and ripening. This rapid change from the unripe to the ripening state is known as the climacteric phase. Biochemical studies reveal that a whole series of chemical reactions is now

proceeding rapidly. These include a decrease in total dry matter, the hydrolysis of starch, an increase in sugar content, acidity and glycoside glucose, and many other interesting changes. As the fruit becomes eating-ripe, over-ripe, and finally senescent, the several curves for respiration rate, percentage sugar content, etc., are found to follow characteristic trends.

An important aspect of this work was to investigate the relationship between respiration rate and change in chemical composition during ripening. In the laboratory, as observations of rate of respiration are usually carried out continuously on single fruits, such fruits are not available for chemical analyses. This difficulty was overcome by a simple device. It was found that by inserting small tubes into the banana fruit, samples of the internal atmosphere could be withdrawn and analysed (carbon dioxide and oxygen); measurement of the carbon dioxide liberated at the fruit surface could also be obtained from the same fruits (figure 1).

It was found that the climacteric rise in carbon dioxide output was slightly preceded by a sharp

rise in the internal concentration of carbon dioxide and by a marked decline in the oxygen concentration. In brief, the curves of internal concentrations of carbon dioxide and oxygen in individual fruits, under controlled conditions of temperature and humidity, yielded exact information of the stage of ripening reached at any particular time. Fruits at a known state of ripeness were thus available for biochemical analysis. By using a sufficient number of strictly comparable fruits it was thus possible to correlate closely respiration and biochemical data. Some typical results are illustrated in figure 6. Many other points of interest were also brought to light. For example, it was found that during the post-climacteric period the softening tissues offered greater resistance to the movement of gases, and a negative pressure, which could be measured by means of a manometer, was developed within the fruit.

The effect of prolonging the cold-storage period beyond that usual for each grade, and the chemical nature of the abnormalities in the eating and other qualities associated with the resulting chilled condition, have been investigated. There is evidence, from both respiration and biochemical studies, that those fruits which show 'physiological injury' have already begun to ripen during the cold-storage period. Ripening does not, however, follow the normal trend: the skin colour becomes abnormal (a rich bronze colour may develop) and the pulp flavour is poor, astringent, and flat. The biochemical changes involved are complex and obscure, but it is known that the rate of starch hydrolysis is low as compared with that in normal fruits, and the acid and glucoside content tends to be high. Extreme chilling results

in a very marked retardation of ripening and, in extreme cases, in failure to ripen.

With the onset of ripening the several associated fungi become active. Some of these are no more than saprophytes capable of exploiting the ripe sugary tissues of skin and pulp after gaining access through cuts and abrasions. Much more interesting and in some ways more important fungi are those which have long been established in the epidermal cells of the pulp and skin as latent infections. Of these the most significant commercially are *Gloeosporium musarum* (the anthracnose fungus) and *Piricularia grisea* (causing pitting disease). Once these organisms have penetrated the epidermis of young fruits, the living cell, in which the small fungal germ-tubes persist, constitutes the environment of the fungus. In this environment, during the long period of growth to harvesting maturity, the fungus apparently remains in a static condition. But with the arrival of the post-climacteric phase, and the attendant changes in the physical and chemical state of the tissues, the environment becomes favourable to the further growth of the pathogenic organism: it now spreads to neighbouring epidermal cells and into the tissues below, producing characteristic lesions. Such latent infections, their development during ripening, and their control, still require investigation. One of the most interesting points so far noted is the regularity with which the appearance of anthracnose spots coincides with a certain stage of ripeness as ascertained by observation of the internal gas concentrations. In the banana and papaya, for example, it is possible to predict, from a knowledge of the trend of the internal concentration of oxygen, exactly when anthracnose spots will

appear. In passing, it may be noted that latent infections of *Gloeosporium* and other fungi may be a serious cause of wastage in avocados and mangoes. In both of these, as also in the banana, chilling injuries render the fruit much more susceptible to the development of this disease.

GAS STORAGE

The essential feature of transporting bananas in refrigerated holds is to delay the onset of ripening until the fruit is discharged at its destination. With relatively thin grades, harvested

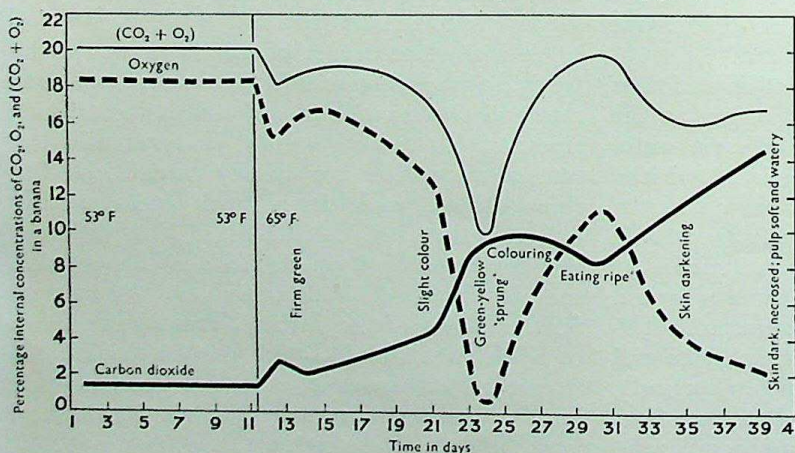


FIGURE 6—Internal concentrations of CO₂, O₂, and (CO₂ + O₂) in a heavy three-quarters full Gros Michel banana during cold storage and ripening.

three-quarters full, this can usually be achieved by refrigeration alone during a voyage of up to sixteen or seventeen days. Heavier grades of fruit, described as 'full' and 'heavy full,' however, begin to ripen during a similar period and chilling injuries result. Yet, as we have seen, there are good reasons why the transport of such grades of fruit should be attempted. It has been suggested that gas storage in conjunction with refrigeration, which has already proved successful with apples, might also be applicable to the banana. In fact, several workers have shown that this useful result may well be realized. Success would mean that a larger and possibly a better banana could be made available on the present markets, or that the present grades could be transported from more distant centres of production. The same methods may also be extended in due course to other tropical fruits, e.g. mangoes, avocados, etc.

Observations have been made on the retardation of ripening effected in heavy grades of fruit by refrigeration at 53° F in conjunction with different supplied gas mixtures, and by artificial atmospheres produced by restricted ventilation. In these experiments the trends of the internal gas concentrations during storage and ripening were ascertained and proved of great interest and value. Only the briefest indication of the data obtained can be given here. In heavy three-quarters full fruit, rapidly cooled to 53° F and held at that temperature for twenty days, gas mixtures containing 5 per cent. carbon dioxide and 7-12 per cent. oxygen produced a notable retardation of ripening without injurious effects, the best results being obtained at the lower oxygen concentration. The fruits were subsequently ripened in air in the normal way. As compared with the control fruit in air, in which severe chilling injury was sustained, the gas-stored fruit ripened to a good yellow colour; it showed no evidence of chilling, the palatability, bouquet, and mealy 'break' being those of

normally ripened fruit. The different metabolic trends of gas-stored fruit as compared with fruit in air are clearly illustrated in figure 7. In somewhat similar experiments, heavy three-quarters full fruit was stored in oxygen concentrations of 6 and 12 per cent. (in nitrogen). The ripening data showed that a reduction in oxygen concentration from 21 per cent. to 12 per cent. did not afford adequate retardation of ripening during cold storage, whereas a reduction to 6 per cent. afforded a good retardation without injurious effects. Conclusive evidence was obtained that where ripening had already begun, refrigerated gas storage was ineffective: the fruit continued to ripen during cold storage. An important point, particularly from the commercial standpoint, was that although this fruit ripened to a product of excellent colour and texture, the pulp was flavourless. Even high concentrations of carbon dioxide and low concentrations of oxygen did not retard the ripening of heavy grades of fruit in which ripening had already begun.

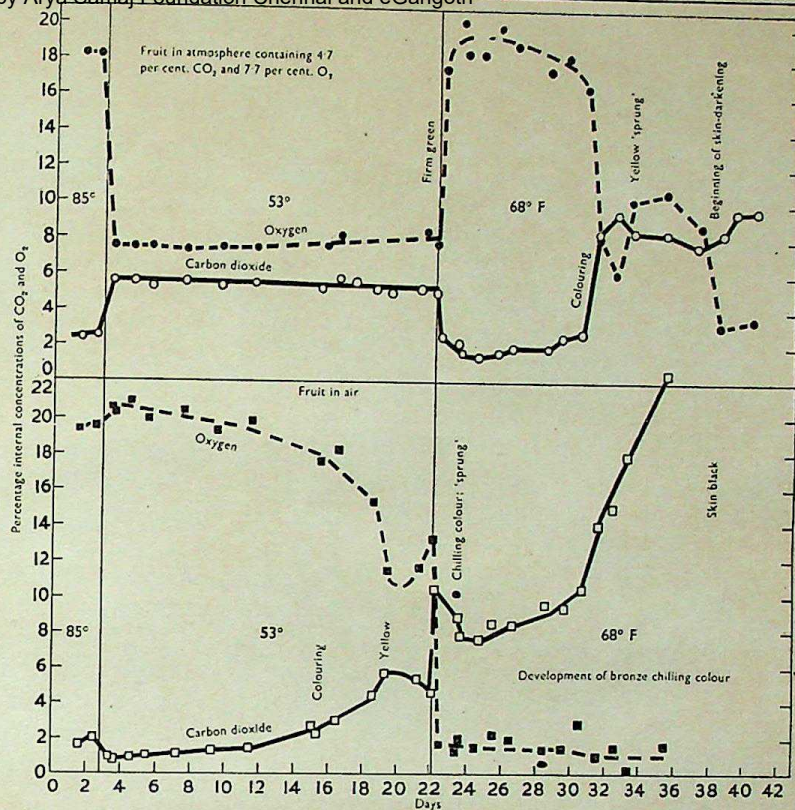


FIGURE 7 - Storage of bananas (gathered at 85° F) in an artificial atmosphere (above) and in air (below) at 53° F, followed in both instances by ripening in air at 68° F. The fruit stored in air became chilled and showed abnormal trends in the internal concentration of O₂ and CO₂: gas-stored fruit was normal.

As in other instances where gas storage has proved commercially feasible, it may be anticipated that, in arriving at a suitable artificial atmosphere for bananas, use will be made of the changes in atmospheric composition which result from respiratory processes, i.e. an increase in carbon dioxide and a decrease in oxygen. It has, in fact, been shown that this kind of procedure is feasible, and that suitable refrigerated gas-storage conditions could be achieved in the course of the first or second day from loading (at tropical temperatures, 80-85° F), provided gas leakage was negligible. It may therefore be anticipated that the commercial gas storage of bananas will be achieved by a system of restricted ventilation in conjunction with the removal of excess carbon dioxide by chemical means. In systems of this kind, the part played by physiologically active volatile substances, such as ethylene, liberated from ripening fruit and known to accelerate ripening, may be of critical importance. In laboratory experiments, heavy three-quarters full fruit has been satisfactorily stored for twenty days at 53° F, using the method of restricted ventilation. On being removed from the containers the fruit was still quite green, subsequently ripening to a product of good colour, flavour, and aroma, whereas the control fruit underwent some ripening during cold storage and was severely chilled. But in comparable experiments where heavier grades of fruit were used, the occasional ripening fruit, by giving off ethylene, accelerated the ripening of the aggregate of fruit in the container. The next stage is to extend the experimental work to large-scale batches of fruit. In due course data will be available for the construction of ships' holds suitable for the gas storage of tropical fruits. Provided no other factors intervene, the bigger and better banana, in fact, should soon be available.

OTHER TROPICAL FRUITS

Thus far, reference has been made chiefly to the banana, by way of indicating some of the problems that arise in relation to the overseas transport of tropical fruit. We have, however, merely touched on the fringe of the subject. Each kind of fruit presents its own particular problems; variety, harvesting maturity, handling from plan-

tation to ship, cooling, transport temperature, avoidance of chilling, ripening, and the control of wastage. Different varieties may require different storage temperatures, for example avocado and mango. The same variety grown under different environmental conditions may also require different storage temperatures, for example grapefruit. With avocados and mangoes a not inconsiderable part of the task of the refrigeration biologist has been to select from the vast assemblage of species and varieties those which possess both appearance and quality and also keeping quality in storage. Where the storage temperature is relatively high (for example 55-60° F), the control of fungal wastage presents serious difficulties, since many tropical fungi grow readily at temperatures above 55° F. In fact, a nice balance has to be struck between the danger of chilling on the one hand and the onset of fungal wastage on the other. There is also the added difficulty that, on ripening at higher temperatures, chilled fruit is more subject to fungal wastage. Limes may be cited as an example where the actual refrigeration problems are simple, the main difficulty being to prevent excessive transpiration, i.e. loss of water by evaporation.

The reader may perhaps wonder how the export of tropical fruits is likely to be affected by the increased use of air transport, with all its advantages of speed. Air transport obviously provides the ideal means of curtailing the time between harvesting and retailing, and for handling the small preliminary consignments with which new ventures must necessarily begin. It is a fact of experience that the absence of suitable refrigerated shipping, capable of carrying small experimental lots of fruit exactly as required by the scientific investigator, has been a serious handicap to the development of fruit export industries during the past twenty to thirty years. Air transport affords, as it were, the heaven-sent means of overcoming many of the difficulties that arise in connection with the export of tropical fruits. Bulky materials such as bananas or grapefruit are, of course, ruled out; but as a means of transporting sample quantities of exotic fruits in their pristine condition during the establishment of new industries, the transport aeroplane may well come to occupy an important position.

REFERENCES

[1] WARDLAW, LEONARD, and BARNELL. Memoirs Nos. 1-22 of the Low Temperature Research Station, Imperial College of Tropical Agriculture, Trinidad, B.W.I. (1935-45).

[2] *Idem*. 'Studies in Tropical Fruits,' pts. i-xvi, *Ann. Bot.*, 1936-45.

A PHYSIOLOGICAL TRIBUTE

The Integrative Action of the Nervous System, by Sir Charles Sherrington. Pp. 433. Cambridge University Press. 1947. 25s. net.

To reprint Sir Charles Sherrington's *Integrative Action of the Nervous System* must have been a rare pleasure to the Physiological Society, for in choosing this way of marking the International Congress of Physiology, recently held at Oxford, it has not merely paid the most graceful of tributes to the book's venerable author but has honoured British physiology, the lustre of which in our day is in so large a measure the reflection of Sherrington's genius.

To those newly embarked upon the study of physiology in 1906, when 'The Integrative Action' was first published, the book was an inspiration and a stimulus that it is difficult even now to recall without again feeling the sense of excitement that rises within us at the recognition of a work of genius. Indeed, it was impossible for the critical reader not to realize that here was one of the rare records of achievement and thought in the realm of science that would in time come to take its place with Newton's *Principia* and other works of that high order, as a book that would live however far the advance of knowledge might lead us.

Here were new facts in abundance, and how beautifully co-ordinated! With what logical precision their exposition advanced from step to step, and with what penetrating scientific imagination was their significance revealed! The researches which went to the making of this book remain the foundation upon which every young neurophysiologist must still build, and the rhythm of observation and interpretation that Sherrington's work has always displayed is in the true tradition of natural philosophy.

In its new form this classic book, therefore, should invigorate the work and thought of new generations of physiologists and help to save them from the chains of an unimaginative technology which so easily weigh down the spirit of the young scientist in this age of immense technical ingenuity, when it has become difficult to contemplate the facts of observation with the leisure and calm that their philosophical synthesis demands.

F. M. R. WALSH

NEWTON AND THE MINT

Newton at the Mint, by Sir John Craig. Pp. viii + 128, with 4 plates. Cambridge University Press. 1946. 7s. 6d. net.

In 1696 Montagu—later Lord Halifax—then Lord of the Treasury, wrote to Newton: 'I am very glad that at last I can give you a good proof of my friendship and the esteem the King has of your merits' and offered him the post of Warden of the Mint. Newton, who had for some time been seeking a comfortable administrative post, accepted, and after three years was raised to the chief post, that of Master. The last third of his life was thus passed at the Mint. He took his work there very seriously, and any complete survey of the life of this enigmatic man must take account of that period, which has not received much attention from his biographers.

The information which has hitherto been lacking is furnished by Sir John Craig's little book on Newton's work at the Mint, which is written with expert knowledge. It explains the peculiar constitution of the Mint at the beginning of the eighteenth century and the various responsibilities which fell to the Warden and Master. In this book we see Newton as anything but the dreamy and unworldly sage some of his admirers have depicted: he undertook with great efficiency complicated administrative problems, he laid stress on the keeping of clear records, and he seems to have been a shrewd judge of men. We may regret that such a man should have occupied himself with such things, but we must remember that it was apparently at his own wish. One *Principia* and one *Opticks* are perhaps all that we have a right to expect of one man. E. N. DA C. ANDRADE

TEXTILE FINISHING

An Introduction to Textile Finishing, by J. T. Marsh. Pp. xv + 552. Chapman and Hall Limited, London. 1947. 35s. net.

In writing this book the author has undertaken, with unquestionable success, the onerous task of collecting and presenting in a systematic manner the technical and scientific aspects of an extremely wide branch of textile manufacture. The difficulty of selecting a suitable division of the many branches of the subject has largely been overcome by the judicious use of material or process as subject-matter for each chapter.

Thus the main finishing processes of wool are described under permanent set, milling, and unshrinkable finish. Finishing materials, such as starch, cellulose derivatives, formaldehyde, and rubber, provide the headings of other chapters. Finishing machinery, anti-shrink methods, and the processes of crêping, softening, weighting, and delustring are adequately described. Especially useful are the theoretical and practical treatments of wool finishing and, as is to be expected, of the internal and external application of polycondensates, in which field the author has made a major contribution. The proofing of textile materials against water and attack by moth, mildew, and fire is comprehensively reviewed. References to the literature are fairly adequate but somewhat lacking in completeness of documentation. The diagrams are numerous and appropriate, although a few lack clarity (e.g. with reference to the path of the fabric under treatment) owing to over-simplification and their small size. The book is well printed and practically free from typographical errors. Mr Marsh is to be congratulated on a further valuable contribution to the literature of textile chemistry and technology. F. O. HOWITT

CELLULOSE CHEMISTRY

The Methods of Cellulose Chemistry, including Methods for the Investigation of Substances associated with Cellulose in Plant Tissues, by Charles Dorée. Second edition, revised and enlarged. Pp. xii + 543. Chapman and Hall Limited, London. 42s. net.

The earlier edition of Dr Dorée's book very successfully provided a description of the important methods used in the investigation of cellulose. The author has now increased the indebtedness of all sugar chemists to him by the publication of a new edition which incorporates the advances of the past fifteen years. Extensive additions and alterations have been made, as for example in the section on oxycellulose, which now includes accounts of the oxidation of cellulose with reagents such as permanganate, periodic acid, and nitrogen dioxide. There are sections on the mixed esters of cellulose and on the various ethers, in addition to full treatment of the methods used for acetates, nitrates, xanthates, and other esters. In Part III the reader will find an up-to-date account of the methods used in

the investigation of the hemicelluloses, lignin, and pectic materials. Industrial aspects are well covered, and in addition to analytical procedures for cellulose and its derivatives, including regenerated cellulose, there are chapters devoted to the analysis of wood and wood pulp. The information given is often not readily available in the literature (to which copious references are given), and the methods are accurately described with abundant notes and illustrations. Misprints and errors are few, and the book is a pleasure to read and handle. It will be indispensable to chemists engaged in these fields of investigation. E. L. HIRST

THE PRINCIPLES OF CHEMISTRY
A Rational Approach to Chemical Principles, by J. A. Cranston. Pp. vii + 204. Blackie and Son Limited, London. 1947. 8s. 6d. net.

It is a pleasure to recommend this useful book because of the intelligent point of view from which it has been written. The author begins with a brief summary of atomic structures, referring to quantum levels and electronic configurations. Then follows the orthodox theory of the gaseous state, liquids and solutions, a section on valency theory and energy changes (thermochemical), one on changes involving the consideration of electrode potentials, and finally the study of chemical equilibria, including ionic dissociation.

The scheme is quite attractive and the book is well written. It contains nearly all the general and physical chemistry needed for the Higher School Certificate and university scholarship examinations. The treatment is probably not full enough for it to serve as more than a class-book, however, and there are some omissions, such as order of reaction, indicators, and the determination of hydrogen ion concentration. The aim has been simplicity and clearness, and here and there things are made to look rather easier than they should be. The treatment of electrolysis is sketchy, and the view that uncharged sulphate ions can react with water or are even discharged at all is surely now generally abandoned. The same may be said of sodium ions. In this, and the too-brief reference to the complete dissociation of strong electrolytes, the book is disappointing; in most other respects it is in refreshing contrast to many other works covering the same ground.

A. E. BELL

Co-operative Research in Industry, by D. W. Hill. Pp. 147. Hutchinson's Scientific and Technical Publications, London. 1946. 10s. 6d. net.

The foods and materials Britain has to import now cost so much more than previously that her only chance of paying for them, argues Dr Hill, is to export brains in the form of improvements to manufactures achieved through research. Fortunately, the war showed she need not despair of doing this, for so remunerative is properly co-ordinated research that two or three fundamental inventions might well replace the whole of the capital wealth expended during those years. In that integration co-operative laboratories are a necessity, not to supersede those of individual firms concerned with competitive products but to support and stimulate them through researches on 'standard products common to the industry, the study of generally used raw materials, the improvement of standard processes and methods, the introduction of testing procedures.' The author gives an admirable account—much fuller than a mere list—of the development and organization of laboratories existing with these objects under the Department of Scientific and Industrial Research, the trade research associations which it supports, and others which are independent, including those concerned with agriculture. Later chapters describe the corresponding bodies in the overseas Empire and those, on interestingly different lines, in the United States.

Dr Hill does not, however, define research or explain to the uninitiated how it differs from other laboratory work. His statement that 'the change from the England of Queen Elizabeth to the England of today springs from the knowledge hardly wrought by research' would be truer if 'Victoria' were substituted for 'Elizabeth'; for this is to stretch the term to cover fortuitous profiting from experience as well as those purposeful programmes of research to which the quicker tempo of our own times is mainly due. Some clarification of this point would have improved a valuable book, as would greater emphasis on the importance—equal to that of the actual experimenters—of those concerned with editing, disseminating, abstracting, and indexing scientific papers, and whose function is to harmonize different lines of research.

J. E. HOLMSTROM

BRITISH BIRDS

Our Bird Book, by Sidney Rogerson and Charles Tunnicliffe. Pp. 128, with many coloured illustrations. William Collins, London. 1946. 21s. net.

Mr Rogerson knows a great deal about birds, and he writes about them in a pleasantly informal manner. This is largely a book of personal reminiscence and anecdote; yet, within a small compass of words, it is astonishingly complete. The reading of it would give a child a really good introduction to a life-time's hobby, and the sort of introduction that is wanted—the introduction to the bird as an individual. Charles Tunnicliffe's drawings are true portraits of birds, delightfully crisp and full of life. It has been said with truth that Lewis Carroll's Alice cannot be fully appreciated before one is 40. Childhood has no age-limit, and this, too, is a book for children of all ages. It certainly deserves a place on the shelf of every bird-lover.

BRIAN VESEY-FITZGERALD

THE CHEMISTRY OF FATS

The Chemical Constitution of Natural Fats, by T. P. Hilditch. Pp. xiii + 554. Chapman and Hall Limited, London. Second edition. 1947. 45s. net.

It is seldom that a research worker can be in the happy position of writing, on a group of natural products of great industrial as well as academic interest, a textbook which is very largely an account of his own work. During the past thirty years no name has been more closely associated with the chemistry of fats than that of Hilditch, and when the first edition of his book appeared in 1940 it was acclaimed as a masterly interpretation of his own researches, which had for twenty years or more been centred on the structure of glycerides. The new edition contains much new material from recent publications, and opportunity has been taken to rewrite or partly to rewrite certain chapters. Besides the more amplified data now presented on the component acids and glycerides of natural fats, the author gives a full presentation of the present position with regard to the constitution of the individual fatty acids and the broad field of the biochemistry of fats. The book is the most authoritative statement of the chemistry of fats that has yet been produced, and is likely to remain so for many years to come.

A. C. CHIBNALL

A quarterly review designed to record the progress
of the sciences in the service of mankind

VOLUME VII

APRIL 1948

NUMBER 26

Macromolecules

Of all natural phenomena, life is the most enigmatic. 'The proper study of mankind is man' is an aphorism which the scientist might reasonably interpret within his own sphere as implying that the principal aim of science is the explanation of that complex of properties which distinguishes the quick from the dead. There are many approaches to the problem, but organic chemistry has hitherto proved the most successful. This is no doubt one of the reasons why it has never lacked a host of enthusiastic disciples: organic substances are so closely related to life and to fundamental human needs that they possess a fascination totally different from that of inorganic compounds.

A few decades ago, however, organic chemistry seemed to have reached an impasse in its revelation of the mechanism of life. A student of the subject could find satisfaction in the vast accumulated knowledge of the preceding hundred years, which had settled beyond doubt not only the constitution of such simple bodies as benzene, urea, acetic acid, alcohol, acetone, and so forth, but that of much more complicated substances, including several alkaloids, terpenes, and natural colouring matters. This satisfaction was, however, damped by the disappointing fact that many organic compounds of the greatest importance and interest—for example proteins, rubber, and starch—could be described only in general terms. The outlines of their structures were known but the details were obscure, and the possibility of synthesis seemed far distant. Thus in the field of protein chemistry successful attempts had been made to join together a few amino-acids to form simple polypeptides; but, valuable though the work was in confirming and extending our knowledge of proteins, only the most sanguine chemist could seriously believe that a mere extension of this process could lead to a satisfactory method of synthesizing proteins. The same problems were encountered in

every other field of organic chemistry which involved the study of very large molecules; the available methods were inadequate either to disclose the full details of the structure, or to hold out any promise of synthesis even if the structure could be determined. It was clear that the science had temporarily overreached itself, and was entering regions for which it was not yet properly equipped.

The difficulty proved only temporary and, as has often happened in the past, fresh progress resulted not only from the applications of existing knowledge but from wholly new inspiration and improved techniques. The principal need was for more fruitful methods of elucidating the structure of large molecules and of synthesizing them. It was not long before the need was met. Outstanding among the new techniques is the method of X-ray analysis, which has proved of fundamental value in determining the nature of the repeating unit in long-chain molecules and, in its latest form, has proved capable of establishing the complete atomic configuration of very large but not polymerized molecules such as those of cholesterol and penicillin.

Another very valuable instrument for the investigation of large molecules is the ultracentrifuge, the development of which has been carried out chiefly by the team of investigators headed by The Svedberg, whose article on this subject was published in ENDEAVOUR in 1947. Yet another extremely fruitful method of analysis, especially for proteins, is the method of partition chromatography developed by A. J. P. Martin and his collaborators (ENDEAVOUR, January 1947). This has made practicable the quantitative analysis of proteins in Lilliputian quantities—far smaller than would have been considered necessary even five years ago. Application of the method has already yielded a great deal of information about the order

of amino-acid residues in a number of different proteins, together with other structural details, and it is evident that it has immense possibilities for investigating problems in this field.

Work on the synthesis of macromolecules has kept pace with that on their analysis. Forty years ago relatively little was known about the mechanism of polymerization and there was no market for artificial polymers. In most cases polymerization was regarded merely as a tiresome side reaction interfering with more important studies. Today the picture is entirely different. Greatly increased knowledge of the structure of natural polymers has advanced theoretical chemistry and at the same time has led to an increase in the number of practical applications of these substances. The manufacture of polymers has become an important branch of chemical industry, and many of the new products are important factors in our everyday life.

These noteworthy results have been achieved partly by the perfection of new analytical and synthetic processes and partly by the evolution of a new mental attitude towards the synthesis of large molecules. The impracticability of successively linking small units, such as sugars or amino-acids, to form very large molecules, the molecular weight of which may be measured in tens of thousands, has been recognized. Instead, attention has been focused on ways of making simple substances polymerize smoothly and rapidly without the occurrence of unwanted side reactions. Artificial rubber, Perspex, polythene, and silicone resins are but a few among scores of polymers which have been developed during the last few years.

It remains to be seen to what extent the controlled polymerization of simple substances, or of mixtures of simple substances, can be used for the exact synthesis of natural polymers such as proteins. We know that although many natural polymers may consist of relatively few different kinds

of unit—a dozen different amino-acids, for example—the order and frequency in which these occur may be very complex. To achieve precisely the same order and frequency by direct polymerization of the simple units would need more delicate control than can yet be achieved. At present, the most that can be done is to synthesize polymers which possess the same general atomic configuration, and consequently the same kind of properties, as natural polymers. It may well be that the precise duplication of natural polymers in the laboratory must await the development of methods as yet unknown.

The main article in this issue is by Professor Linus Pauling, who discusses antibodies and specific biological forces—a field in which his own contributions are well known. This article both illustrates the extent of our knowledge of macromolecules and shows how closely connected are branches of science which only a few years ago appeared to be diverging rather than converging. The quantum theory, advanced originally to explain certain peculiarities of black-body radiation, proved invaluable in elucidating the nature of the chemical bond. An understanding of the forces which bind atoms and molecules together encourages the hope that it will eventually be possible to express the phenomena of life in terms of the molecular structure of the organism. Few problems are of more contemporary importance in science, and none is of greater practical importance in medicine, than an understanding of the relationship between antibody and antigen. That it is now at length possible to discuss this relationship in terms of established scientific theory is a measure of the speed with which the study of macromolecules has advanced during recent years. Another milestone has been reached on the road to the elucidation of life, through inventive skill and 'profound thought, the fine balance of truth in observing, with the imaginative faculty in modifying, the objects observed.'

Editor: E. J. HOLMYARD, M.A., M.Sc., D.Litt., F.R.I.C.

Deputy Editor: TREVOR I. WILLIAMS, B.A., B.Sc., D.Phil.

Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1

Antibodies and specific biological forces

Digitized by Arya Samaj Foundation Chennai and eGangotri

LINUS PAULING

Advances in organic chemistry during the past century have made it possible to identify the structure of many of the simple substances found in living cells and to understand such chemical changes as respiration and excretion. Only recently, however, have there seemed sure grounds for believing that knowledge and technique have advanced far enough to permit an eventual elucidation of such highly complex problems as the relationship between antibody and antigen, and other fundamental phenomena of life.

Significant progress has recently been made in the attack on the problem of the nature of specific biological forces, and also on the related problem of the mechanism of manufacture of complex biological molecules with specific properties. For example, animals are able to synthesize various proteins fulfilling special functions—such as haemoglobin, which carries oxygen from the lungs to the tissues. The molecule of haemoglobin is large and complex. It contains about 10,000 atoms, and its molecular weight is 68,000. It has the property of combining reversibly with oxygen, and will react to the presence of carbon dioxide by tending to liberate the combined oxygen. The properties of haemoglobin are not exactly the same for animals of different species, but vary from species to species. The variation is sometimes of such a nature as to be obviously useful to the animal—thus the haemoglobin of cold-water fishes liberates its oxygen at lower temperatures than does that of warm-blooded animals.

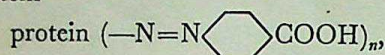
The problem of the way in which an animal is able to manufacture the special molecule of haemoglobin that it needs is part of the general problem of the manufacture of specific biological substances. For example, a virus molecule in the proper environment (that provided by its host) is able to cause the production of replicas of itself, and the phenomena of heredity depend upon the similar autocatalytic action of molecules of genes present in the chromosomes and also in the cytoplasm of cells.

The specificity shown by the synthesizing system in cells in manufacturing haemoglobin molecules of a particular type, or other complex substances with specific biological properties, is observed in many other phenomena. Plants and animals form enzymes which have the special powers of catalysing certain chemical reactions, such as the hydrolysis of a polypeptide chain at the link between two definite amino-acid residues

or the successive stages in the oxidation of foods. A striking example of specificity in properties is shown by antibodies, substances produced by an animal after the injection of a foreign material, the antigen. In general, antibodies produced in response to the injection of a particular antigen have the power of combination with the homologous antigen used in their production, but not with other substances, except those that are very closely related in molecular structure. Thus the problem of the structure of antibodies, in relation to their power of specific combination with the homologous antigen and to the mechanism of their production, bears on both of the basic problems of biology mentioned above.

The work of Karl Landsteiner contributed greatly to the development of the present understanding of the nature of serological reactions. After he had discovered the human blood-groups, Landsteiner began a penetrating series of experimental studies, designed to throw light on the problem of the nature of serological reactions. Most important was his discovery that it is possible to cause an animal to manufacture antibodies with the power of specific combination with various chemical groups of known structure. Beginning in 1917, he and his collaborators prepared artificially conjugated antigens by coupling relatively simple chemical substances to proteins, and then injecting these artificial antigens (usually azoproteins, with structure protein— $\text{N}=\text{N}-\text{R}$, made by coupling a diazotized amine to the protein molecule) into animals. Landsteiner thus produced antisera which were found to contain antibodies with the power of combining with the protein used in manufacturing the azoprotein, and also antibodies with the specific power of combining with the attached group of known structure, which he called the haptenic group. The most useful method for studying the combining power between antibodies and homologous

antigens is the precipitation method—an antiserum mixed in proper proportions with a solution of the homologous antigen forms a precipitate with it, whereas it is not able, in general, to form a precipitate with other substances. For example, Landsteiner prepared an azoprotein by diazotizing *p*-aminobenzoic acid, $\text{NH}_2\text{C}_6\text{H}_4\text{COOH}$, and coupling it with egg albumin, to produce the azoprotein



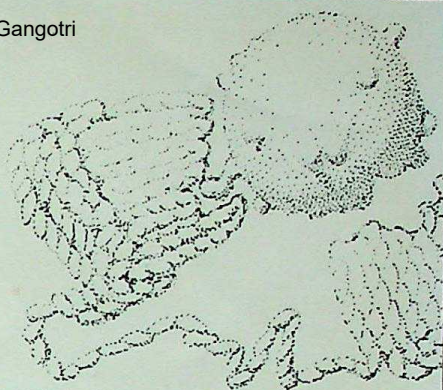
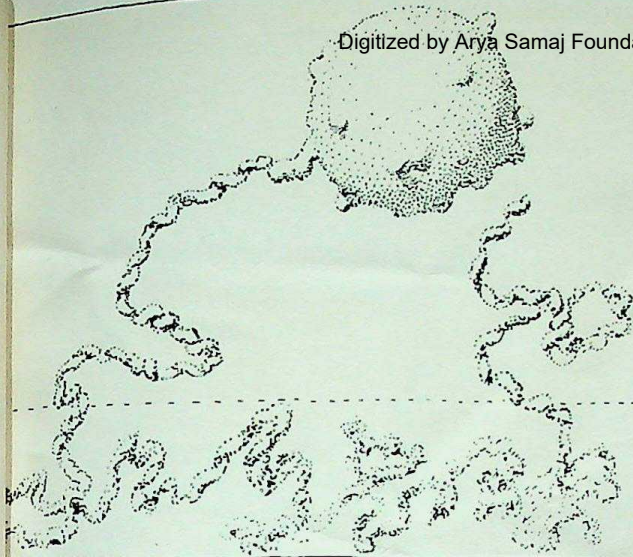
containing several haptenic groups attached to each molecule of protein. He found that the antiserum made by injecting a rabbit with this azoprotein not only had the power of forming a precipitate with a solution of the original azoprotein, made from egg albumin, but could form a precipitate with a solution of an azoprotein made with any other protein, such as bovine serum albumin, by coupling it with diazotized *p*-aminobenzoic acid. This property of precipitation with any azoprotein containing the *p*-aminobenzoate ion group shows that the antibody has developed the power of combining with this haptenic group. The combining power is, moreover, highly (but not completely) specific. The antiserum does not form a precipitate with an azoprotein made by coupling some unrelated substance, such as diazotized *p*-aminosuccinanilic acid, with a protein, but has the power of forming a small amount of precipitate with azoproteins made with closely related substances, such as a substituted *p*-aminobenzoic acid with a group or atom such as methyl or chlorine also attached to the benzene ring. The picture of the structure of antibodies described below had its origin in large part in an attempt to interpret the nature of the serological cross-reactions observed by Landsteiner in terms of the molecular structure of the haptenic groups. Landsteiner's work is summarized in his book *The Specificity of Serological Reactions*, the first edition of which was published in 1936 and the second edition (after his death) in 1945 [1].

The following picture of the process of formation of antibodies under the influence of a molecule of antigen was developed during a vigorous effort to imagine the simplest structure that could be suggested, on the basis of the information available about intramolecular and intermolecular forces, for a molecule with the properties observed for antibodies, and also to imagine the simplest reasonable process of formation of such a molecule [2]. This theory of the structure and

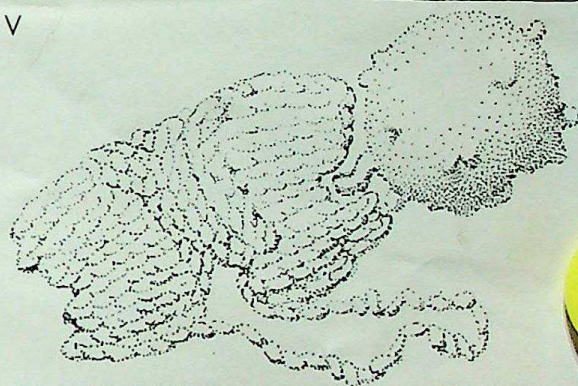
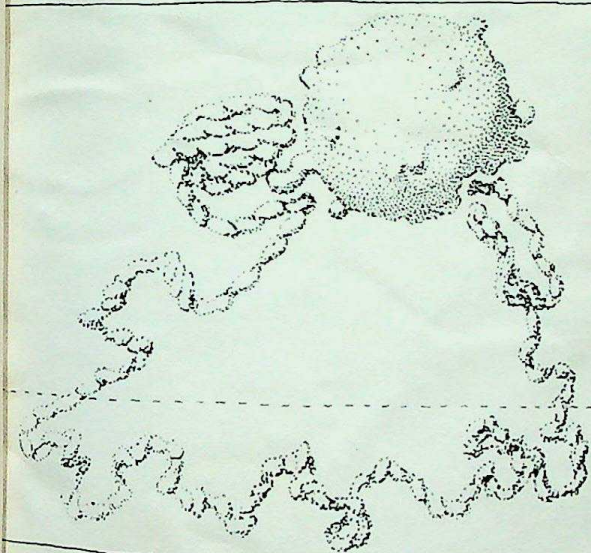
process of formation of antibodies is based upon the concepts that the forces between an antibody and its homologous antigen are the ordinary short-range forces known to exist between simpler molecules, and that the great specificity results from a detailed 'complementariness' in configuration extending over a considerable surface of the antigen molecule and the corresponding combining region of the antibody molecule. The concept of specificity of serological reactions as resulting from complementariness in structure was originally suggested by Breinl and Haurowitz [3], and was then independently presented by Jerome Alexander [4] and Stuart Mudd [5]. There is some intimation of it in the early work of Ehrlich (the lock-and-key theory), and of Bordet. The concept of the multivalency of antibody molecules and antigen molecules, now incorporated in the theory, is due to J. R. Marrack [6], and support for it was provided by the work of Michael Heidelberger. Many experimental studies carried out at Pasadena since 1940 have provided evidence in favour of the concept of complementariness and also of the multivalency of antibodies.

Let us describe the immediate precursor of a molecule of normal γ -globulin as a polypeptide chain, containing a thousand or more amino-acid residues arranged in a sequence determined by the nature of the system of enzymes and reticular structures constituting the cell in which the γ -globulin is being synthesized. We assume that this polypeptide chain can become either a molecule of normal γ -globulin or a molecule of antibody with specific combining power for an arbitrary antigen, according to the way in which the long and complex polypeptide chain is folded. It seems likely that some native proteins are of such a nature—i.e. have such a sequence of amino-acid residues—that of the many ways in which the chain can be folded one is characterized by being specially stable. This specially stable configuration might be that of the native protein; it is known that certain proteins, such as trypsin and haemoglobin, can lose their specific properties under the action of a denaturing agent, and can then regain them, presumably by re-coiling to the normal, stable configuration as the denaturing agent is slowly removed. However, we assume that the polypeptide chain of γ -globulin is of such a nature that a very great number of alternate ways of coiling the polypeptide chain have nearly equal stabilities. When the polypeptide chain is synthesized in the cell, in the absence of any foreign molecules the chain will tend to coil

IV



V



VI

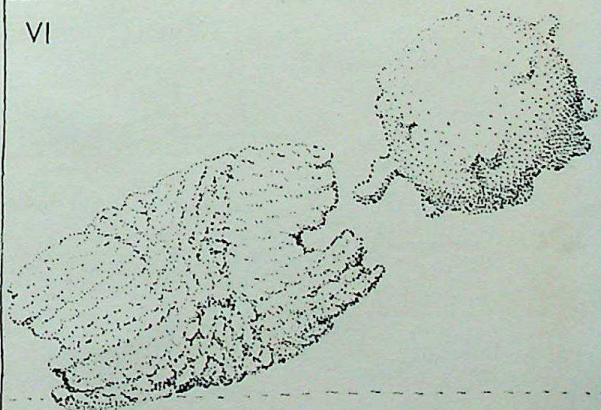
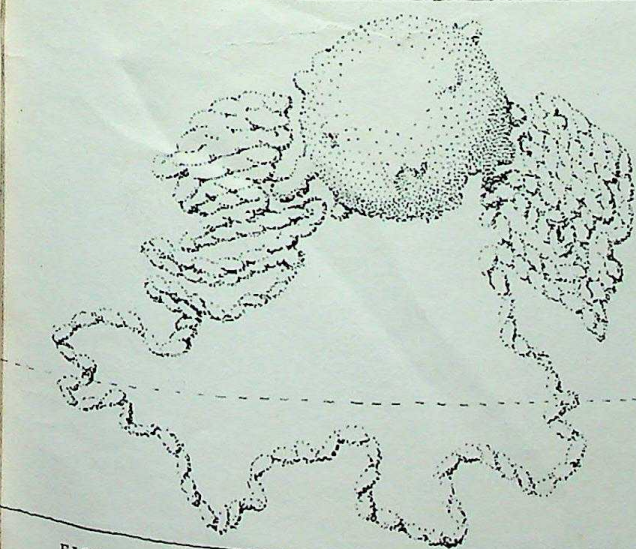


FIGURE 1 - A postulated process of formation of antibody molecules. The polypeptide chain of the antibody precursor is folded, in the presence of an antigen molecule, into configurations complementary to the antigen. (See page 49.)

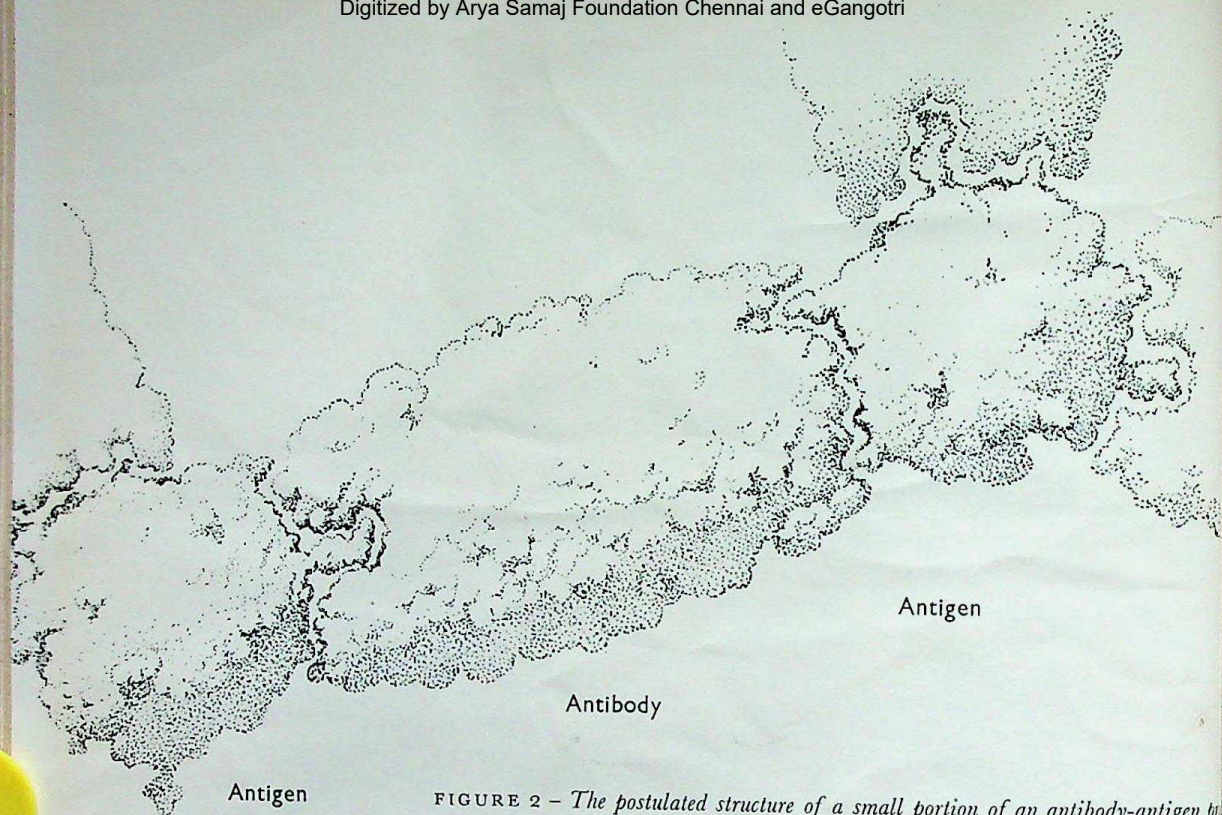


FIGURE 2 - The postulated structure of a small portion of an antibody-antigen complex

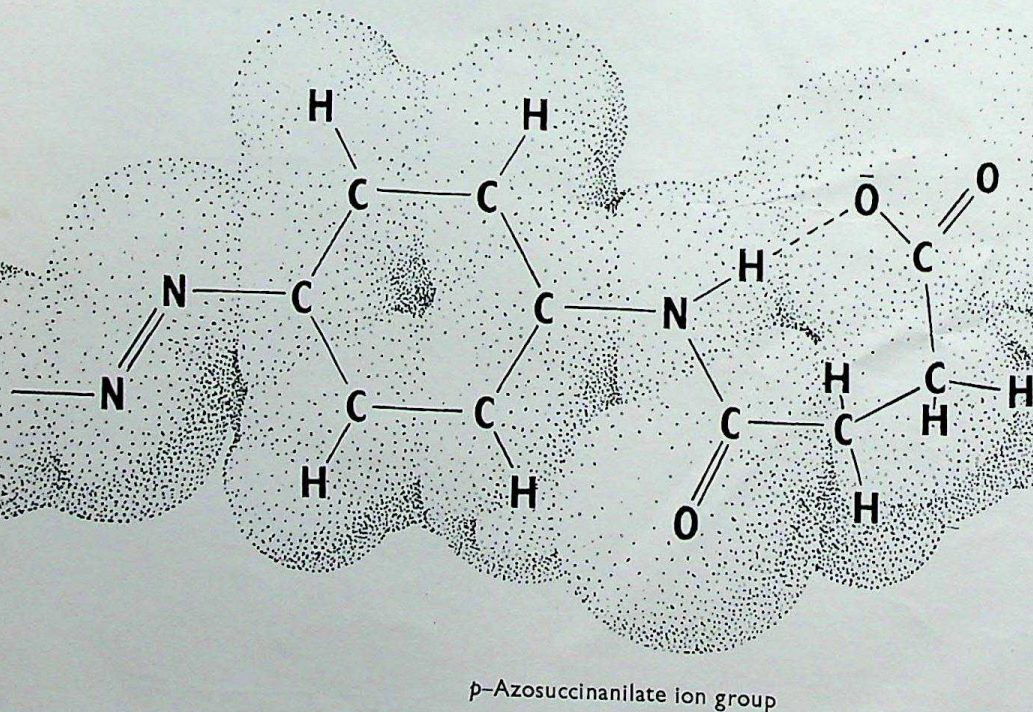


FIGURE 3 - The structure of the haptenic group of an azoprotein, ovalbumin-p-azosuccinilate ion.

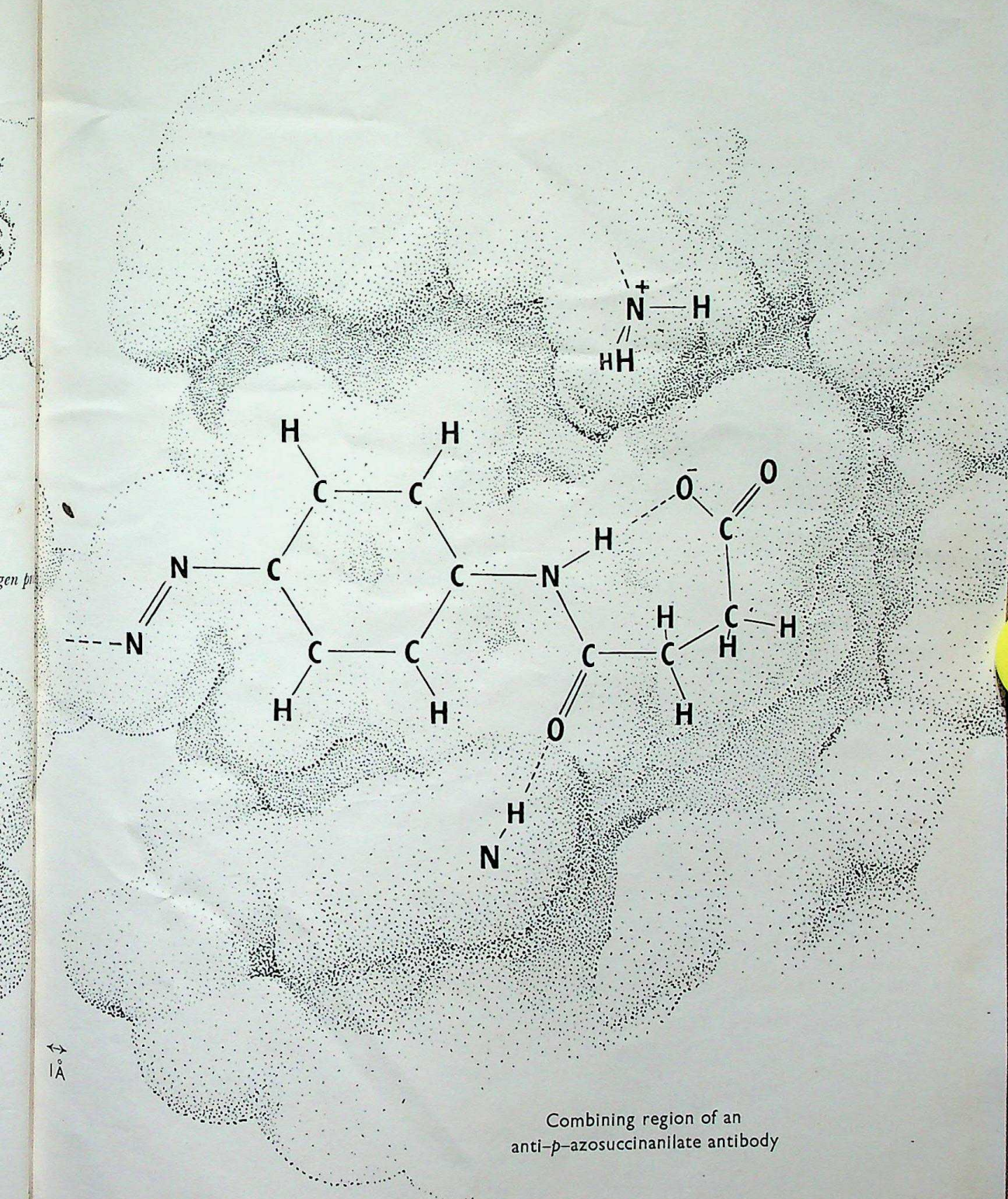


FIGURE 4 - A haptenic group and a complementary region of its specific antibody.

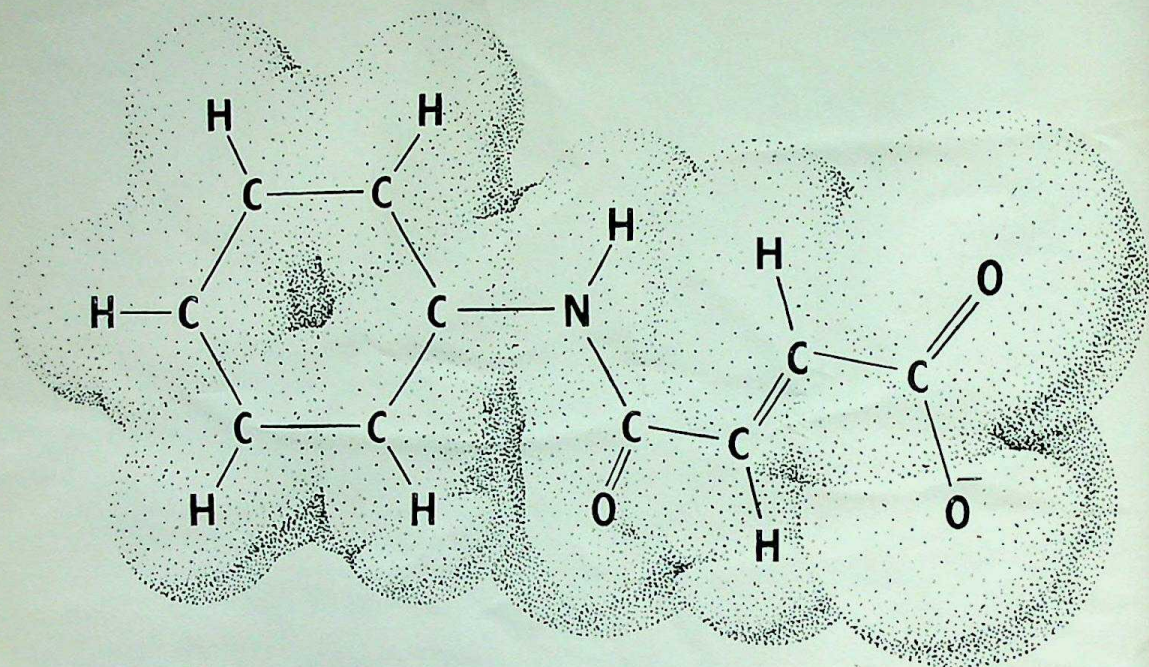


FIGURE 5 - The fumaranilate ion, which has very small combining power with the antibody shown in figure 4.

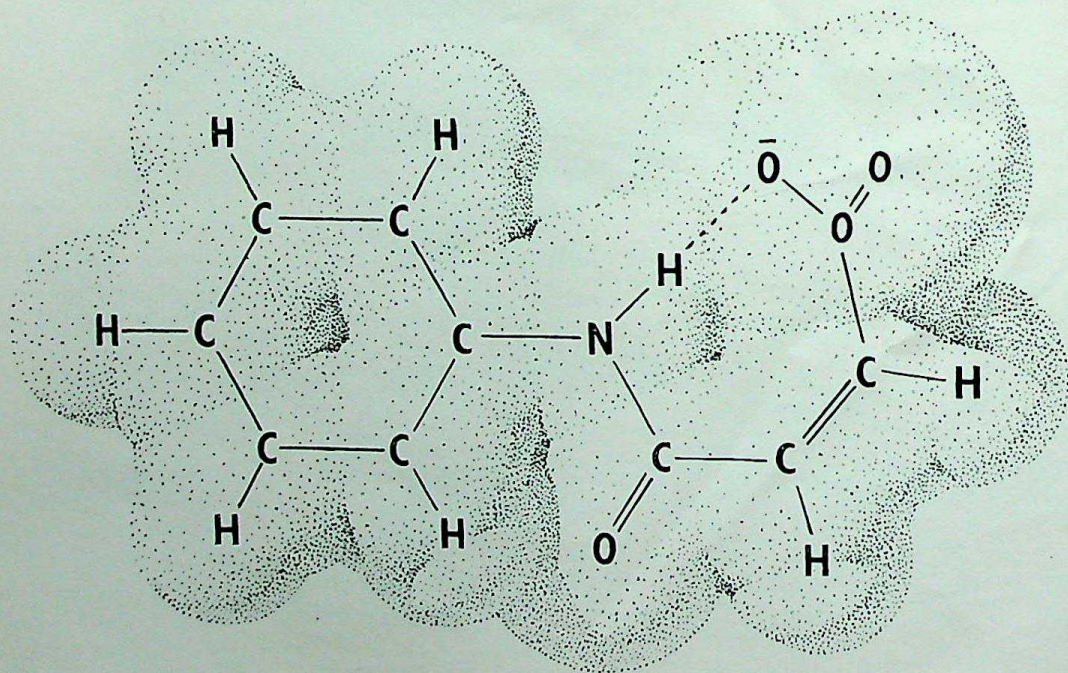


FIGURE 6 - The maleanilate ion, which combines strongly with the antibody shown in figure 4.

into that configuration which is most stable under the normal circumstances within the cell, producing a molecule of normal γ -globulin. If, however, there is present in the cell a foreign molecule, a molecule of antigen, the environment in which the γ -globulin polypeptide chain finds itself is different, and the difference in environment will be such as to stabilize others of the configurations accessible to the polypeptide chain, namely those which have the greatest power of attraction for the antigen molecule. This hypothetical process provides an automatic method by which a molecule is produced that is complementary in structure to a portion of the surface of an antigen molecule. The phenomenon is the same as the production of a coin by a die, or in general of a replica by the process of pressing a plastic material against a mould and permitting it to harden. The polypeptide chain, with its power of assuming alternative configurations, is the plastic material, and the surface of the antigen serves as the die or mould. The process of hardening is the result of the operation of the weak forces between different portions of the polypeptide chain that find themselves in juxtaposition; these weak forces, which individually could not withstand the disrupting effect of thermal agitation, co-operate, after the very large protein molecule has assumed its final configuration, to hold the molecule in that configuration.

In figure 1 the antigen molecule is represented as a roughly spherical aggregate of atoms, with a surface structure shown by protuberances and hollows. One of these protuberances might represent, for example, a *p*-azobenzoate ion haptenic group. The precursor of γ -globulin is shown as being synthesized in a region of the cell separate from that occupied by the antigen (this region being indicated by the line of dashes). In the first section of figure 1 two ends of a polypeptide chain are shown as liberated first from this region, and permitted to fold into the most stable of the configurations accessible to them. The ends of these two polypeptide chains are seen in the second section of the figure to be attracted to the surface of the antigen, and to assume configurations that make the forces of attraction between them and the molecule of antigen as great as possible. Inasmuch as most of the forces that are effective between molecules fall off very rapidly with increasing distance, and are strong only over a range of a few Ångström units, the stabilized configurations of the end of the polypeptide chain will be those that bring as large a portion as

possible of each chain-end into immediate juxtaposition with a surface of the antigen molecule; that is, the structures of the combining regions will have as great a complementariness as possible with the surface structure of the antigen molecule. This complementariness includes not only the similarity in the surface configuration but the juxtaposition of special combining groups, such as a negatively charged group in the antibody with a positively charged group in the antigen, and a hydrogen-bond-forming group carrying the proton with a similar group presenting an electron pair.

The third section of figure 1 shows the antigen with two combining regions of the antibody formed. The central section of the polypeptide chain has not yet been folded. In the fourth drawing one of the combining regions of the antibody is represented as breaking away from the antigen, under the influence of thermal agitation; the central section of the polypeptide chain then folds into its stable configuration, fastening the two combining regions of the antibody together into the completed antibody molecule. In the fifth drawing this molecule is shown still attached to the antigen by one of its combining groups; in the sixth drawing the completed antibody molecule is represented as breaking away from the antigen under the influence of thermal agitation, forming a free antibody which may build up the antibody titre of the blood-plasma.

The assumption that most antibody molecules have two regions able to combine with antigen (i.e. are bivalent) accounts for some of the properties of antisera. For example, antibodies homologous to cellular antigens, such as red blood-cells, are able to cause these cells to agglutinate. The serum from humans with blood of type B or O contains antibodies capable of combining with the A antigen, which is present on human red blood-cells of types A or AB. When this serum is added to a suspension of these cells, the red cells clump together. The simplest explanation of this clumping is that an antibody molecule uses one of its combining groups to attach itself to the outer surface of one red blood-cell by combining with the A haptenic group present on this cell wall, and that then, on collision with another red blood-cell, it uses its other combining region to form a bond with the second cell, thus holding the two cells together. This process may continue until all of the cells are agglutinated into clumps. A similar explanation leads immediately to an understanding of the phenomenon of serological precipitation, as was pointed out by Marrack. The antigen

molecule may use various portions of its surface to attach itself to several antibody molecules, as indicated in figure 2, and each of these antibody molecules may then use its second combining group to bind further molecules of antigen. As this process continues, the aggregates of antigen molecules and antibody molecules become larger and larger until finally they constitute a visible precipitate. Thus the phenomena of agglutination and serological precipitation do not require any further explanation, once the power of formation of a specific bond between antibody and antigen has been explained and a mechanism of providing an antibody with two combining groups has been revealed. Not all antisera have the power of serological precipitation; the non-precipitating antisera presumably contain univalent antibodies with only one combining group.

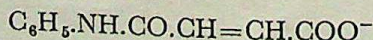
Landsteiner discovered a specially interesting way of studying the degree of specificity of antibodies. He found that when benzoic acid itself was added to an anti-*p*-aminobenzoic acid serum no precipitate was formed. However, a reaction had occurred between the benzoate ions and the antiserum, because when the homologous azoprotein was added to the solution it failed to precipitate with its antiserum, which in the absence of the benzoate ion would have given a precipitate with it. This inhibition of precipitation by the simple haptenic benzoate ion was explained by Landsteiner as resulting from the formation of a soluble complex between the antibody and the benzoate ion. The framework theory of serological precipitation and the assumed bivalency of antibodies immediately provide an explanation of the phenomenon: the bivalent antibody is able to combine with two molecules of benzoate ion, one of which attaches itself to each of its combining groups, but it is not able to form a framework precipitate with benzoate ion, because the benzoate ion ('antigen') itself has the power of combining with only one antibody molecule. The azoprotein antigen, with several *p*-azobenzoate ion haptenic groups, can form the framework in the absence of benzoate ion, but in the presence of benzoate ion all the antibody is tied up in soluble complexes with this ion, and so is prevented from precipitating.

Continuing the work of Landsteiner, Professor Dan H. Campbell, Dr David Pressman, and I, with a number of students, have carried out quantitative studies of the relative inhibiting powers of a great number of haptens, and have in this way obtained detailed information about the

closeness of fit of the combining region of the antibody to haptenic groups of known structure. It has been found that, in general, the replacement of one group by another group that differs in shape from it by as much as one or two Ångström units leads to a significant decrease in combining power with the antibody. For example, the introduction of a methyl group in place of a *meta* hydrogen atom in the benzene ring of the benzoate ion decreases the combining power with an anti-*p*-aminobenzoic acid serum to about one-tenth of its original value. This is explained as the result of a resistance to fitting the larger methyl group, which has an effective radius of about 2.0 Å, into the region which in the process of synthesis of the antibody was occupied by a hydrogen atom of the haptenic group of the immunizing antigen, this hydrogen atom having an effective radius of about 1.2 Å. It has also been shown that a negatively charged group is present in the antibody at very nearly the minimum distance of approach to a positively charged group in the haptenic group of an azoprotein used in producing the antiserum [7].

An example of the degree of the effect of molecular shape on the power of combining with an antibody is illustrated in figures 3-6. Figure 3 gives a representation of the *p*-azosuccinilate ion group, present with many other similar groups in an azoprotein molecule, used in the production of an anti-*p*-azosuccinilate antiserum by injection into rabbits. Figure 4 shows a schematic drawing of the combining regions of such an antiserum, surrounding the haptenic group. It will be noticed that the atoms that constitute the surface of the combining region of the antibody are shown as being in approximate (about 1 Å) contact with the surface of the atoms of the haptenic group. It seems likely that there is still closer approximation of the surface atoms of the antibody and the antigen in many cases, and that the antibody has enough elasticity to permit the introduction of haptens that differ in shape by 1 or 2 Å in linear dimensions from the haptenic group of the immunizing antigen. An ammonium ion group, with a positive charge, is indicated in the drawing as at the minimum distance of approach to the negatively charged carboxyl group of the succinilate hapten, and an >NH group, capable of forming a hydrogen bond with the carbonyl group of the succinilate, is shown in the proper position to form this hydrogen bond.

The maleanilate ion:



and the fumaranilate ion (with the same formula) are closely similar substances, differing only in their spatial configuration, the maleanilate ion having the *cis* configuration about the carbon-carbon double bond and the fumaranilate ion having the *trans* configuration about this bond. These ions were found to differ very greatly in their inhibiting power for anti-*p*-azosuccinanilate serum. The maleanilate ion has nearly as great an inhibiting power as the homologous hapten succinanilate ion itself, whereas the fumaranilate ion has a very slight effect, only about 1 per cent. of that of the maleanilate ion. This power of the antibody to distinguish between two ions of such closely related structure was discovered by Landsteiner, and has been verified through the study of hapten inhibition by hundreds of substances. The relatively small difference in structure of the fumaranilate ion and the maleanilate ion is shown by the drawings in figures 5 and 6.

The importance of a positive charge in the antibody is indicated by the fact that no haptens except those with a negatively charged group—either a carboxyl ion group or a closely similar ion group—have any power of combination with antibodies homologous to the *p*-azosuccinanilate ion. The presence of the indicated hydrogen-bond-forming group in the antibody molecule, shown as combining with the carbonyl group, is verified by the fact that only haptens that contain this carbonyl group have a significant power of combining with the antibody.

It is interesting that a study of serological reactions can be used to provide information about the molecular structure and configuration of simple substances [8]. Thus it might be thought that the *p*-azosuccinanilate ion group, indicated in figure 3, would have an extended configuration, somewhat similar to that shown for the fumaranilate ion, inasmuch as there is considerable freedom of rotation about the carbon-carbon bond. However, from the fact that the maleanilate ion has a large combining power with anti-*p*-azosuccinanilate ion antibodies, while the fumaranilate ion has a small combining power, it can be deduced that these antibodies are complementary in configuration to the maleanilate ion, and that consequently the *p*-azosuccinanilate ion group, which serves as the template for the manufacture of these antibodies, itself has a configuration closely similar to that of the maleanilate ion. This configuration, shown in figure 3, is presumably stabilized, relative to the *trans* configuration, by the formation of an N—H...O

hydrogen bond between the imino group and an oxygen of the carboxyl group. The fact that the succinanilate ion itself, other amides of succinic acid, and the mono-alkyl esters of succinic acid also combine strongly with the antiserum shows that these ions tend to assume a similar *cis* configuration. However, the succinate ion ($^{-}\text{OOC}.\text{CH}_2.\text{CH}_2.\text{COO}^{-}$) has a surprisingly small power of combination with the antiserum—approximately that of the fumarate ion, and much smaller than that of the maleate ion—from which it can be inferred that the succinate ion has essentially a *trans* configuration about the carbon-carbon single bond. An obvious explanation of the stability of the *trans* configuration for this ion is the Coulomb repulsion of the two negatively charged carboxyl groups.

In a preceding paragraph a rather complicated mechanism for the manufacture of antibodies with two combining groups has been described. The existence of these bivalent antibodies is presumably explained by their usefulness in causing the agglutination of cells or the precipitation of molecular antigens. However, the lysis and phagocytosis of cells are aided by the attachment of antibodies to the cells, but seem not to require agglutination; hence this part of the mechanism of protection against disease might be just as well done by univalent as by bivalent antibodies. Similarly the neutralization of toxins is effectively achieved by univalent antitoxins, and the reason for the manufacture by animals of bivalent antitoxins is here also not clear.

Nevertheless the phenomena of agglutination and serological precipitation are striking ones, and it is of interest to see whether they can be explained by the same forces that produce specific combination of antibody and antigen, or whether some additional explanation must be invoked. In suggesting that the first of these alternatives is correct, and that agglutination and precipitation result from multivalency of the antibody, Marrack [6] adduced various experimental observations in support of his proposal. Further support for the framework theory was provided by the work of Heidelberger and Kendall [9].

Recently a striking experiment was carried out, the results of which leave little doubt that the framework theory of serological precipitation and agglutination is correct [10]. Landsteiner and van der Scheer [11] had observed that certain simple substances containing two haptenic groups were able to produce precipitates with the hapten-homologous antisera. It seemed to us likely that

the formation of a precipitate with these substances, containing two haptenic groups, and the failure to form precipitates with substances containing only one haptenic group, which in general have only an inhibiting power, due to the formation of soluble complexes, could be explained directly by the framework theory, and that accordingly a test of the theory could be made by investigating a large number of monohaptenic and polyhaptenic substances. This was done with the use of antisera homologous to the *p*-azobenzene-earsonate ion group [12]. It was found that of the substances tested those containing two or more *p*-azobenzene-earsonate ion groups in the molecule produced precipitates with the antisera, there being about twenty of these substances, whereas the thirty substances tested which contained only one benzenearsonate ion group in the molecule did not form precipitates but rather inhibited precipitation with a precipitating antigen.

The argument might be made, however, that the tendency of the polyhaptenic molecules to form precipitates with the antisera is due to some property other than their polyhaptenic character, and that only one of the haptenic groups may be actually involved in combination with antibody. A test was made by carrying out a special experiment [10], the results of which showed that each of the two haptenic groups of a dihaptenic substance enters into specific combination with antibody in the formation of the serological precipitate.

It was found that antisera could be obtained from two rabbits, and a substance could be synthesized of such nature that neither of the two antisera alone forms a precipitate with the substance, but that a mixture of the two antisera, from the two rabbits, has the power of precipitating with the substance. This serological reaction is, then, one involving a substance of known structure, which serves as precipitating antigen, and two different antisera, which must co-operate in producing the precipitate with the substance.

One of the rabbits was injected with an azo-protein containing R groups (*p*-azobenzene-earsonate ion groups), and the other rabbit was injected with a protein containing X groups (*p*-azobenzoate ion groups). The two antisera are accordingly an anti-R serum and an anti-X serum. Each of these sera is able to form a precipitate with substances containing two or more of the homologous haptenic groups. The two RX substances used in the experiment were made by coupling one R group and one X group to a molecule of known structure; the substances

were 1-amino-2-*p*-(*p*-azobenzeneazo)-benzenearsonic acid-3,6-disulphonic acid-7-*p*-(*p*-azobenzeneazo)-benzoic acid-8-hydroxynaphthalene and 1,8-dihydroxy-2-*p*-azobenzene-earsonic acid-3,6-disulphonic acid-7-*p*-(*p*-azobenzeneazo)-benzoic acid-naphthalene. Each of these substances was found to form no precipitate (or only a very slight precipitate) with either anti-X or anti-R serum alone, but to form a large amount of precipitate with a mixture of these two antisera. This observation provides strong evidence that the precipitation of antibody and antigen involves both the haptenic groups of the dihaptenic antigen. When mixed with anti-R serum alone, a substance RX uses its R groups to combine with the anti-R antibodies, two molecules of RX thus forming a soluble complex with one molecule of bivalent antibody; but because the molecules RX are effectively monohaptenic when only anti-R antibodies are present, a framework precipitate cannot be formed. In the presence of a mixture of anti-R and anti-X antibodies, however, the molecule RX is effectively bivalent, and can form a framework in which the anti-R and anti-X antibodies alternate.

There is now very convincing evidence that the specificity of combining power of antibodies can be explained in terms of short-range forces of known nature, the specificity itself resulting from complementarity in structure of the combining region of the antibody and the surface of the homologous antigen. It seems not unlikely that biological specificity in general is to be accounted for in a similar manner, as resulting from the ordinary non-specific, short-range forces that operate between all molecules, with the specificity of the forces in the biological systems due to the complex surface configuration of the large molecules present in these systems. The evidence as to the nature of the biological forces in systems other than serological systems is, however, not so extensive. Phenomena such as competition between the sulphonamide drugs and *p*-aminobenzoic acid, and the inhibition of enzyme systems generally by substances related in structure to those that take part in the catalysed reaction, suggest, by their similarity to hapten-inhibition of serological precipitation, that the same forces are acting as in the serological systems. For example, the malonate ion serves to inhibit the catalytic activity of the enzyme dehydro-succinase, presumably by competing with the succinate ion for the position of attachment to the active region of the enzyme. The fact that the malonate ion is especially effective as an inhibitor of this catalyst may be significant with respect to

the mechanism of catalytic activity. If the catalytically active region of the enzyme were closely complementary in structure to the succinate ion it would presumably not accelerate the reaction of dehydrogenation of the succinate ion, but would instead retard it, since by combining with the succinate ion it would stabilize this ion, and thus increase the amount of energy necessary to convert the ion into the activated complex for the dehydrogenation reaction. If, however, the enzyme were more closely complementary in structure to the activated complex itself than to the succinate ion, it would decrease the activation energy for the reaction, and in this way speed the reaction up. The effectiveness of the malonate ion in inhibiting the reaction suggests that this ion is more closely similar in structure to the activated complex of the dehydrogenation reaction for succinate ion than is the succinate ion itself, and that it is for this reason that the malonate ion is able to compete effectively with the succinate ion for the position on the active region of the enzyme.

It seems unlikely that the specific differences between related enzymes produced by animals of different species, or between other proteins, such as haemoglobin, are due to so simple a difference in structure as a different way of coiling the polypeptide chains. It is probable that antibodies are unique in using this mechanism alone for the assumption of specific differences, and that other biological macromolecules depend upon more deep-seated changes in structure to produce these differences in specific properties. In particular, I think it likely that in general a mutation is due not simply to a changed way of coiling the filamentous structural unit of the gene nucleoprotein, but to a change in the composition of this unit which affects its catalytic activity in such a way as to permit the controlled manufacture of du-

plicates of itself, with the changed structure. It seems likely that a gene that is damaged by ultraviolet light or X-radiation or other catastrophe in such a way as ultimately to produce a mutant is not itself the mutated gene, but is simply a damaged gene. It might be damaged so badly as to be unable to carry on an essential function in the development of the organism, the damage then being lethal. Or the damage might be of such a nature as to permit the gene to serve as the template and to exercise its other functions so as to produce replicas of itself as it was before it was damaged. Or again it might happen that the damaged gene could carry out its functions and produce new genes of somewhat changed structure, which themselves could serve as templates, until ultimately a steady state was achieved, at which there would be no difference between the gene that served as the template and the gene produced with it as a model. This would be the phenomenon of mutation.

There is at present little reliable evidence as to the detailed nature of the process of production of replicas of complex biological molecules, such as viruses or genes, but it is clear that the phenomenon of production of complementary structures, as in antibody formation, provides a possible mechanism. The manufacture of a replica, of a gene for example, might require the production of an intermediate, the gene producing a molecule complementary in structure to itself, which in turn serves as the template for the reproduction of a replica of the original gene. Some support for this concept is given by the known existence of complementary structures in living organisms, such as the blood-group antigens and their homologous agglutinins, and the mutually complementary substances found in eggs and sperm [13].

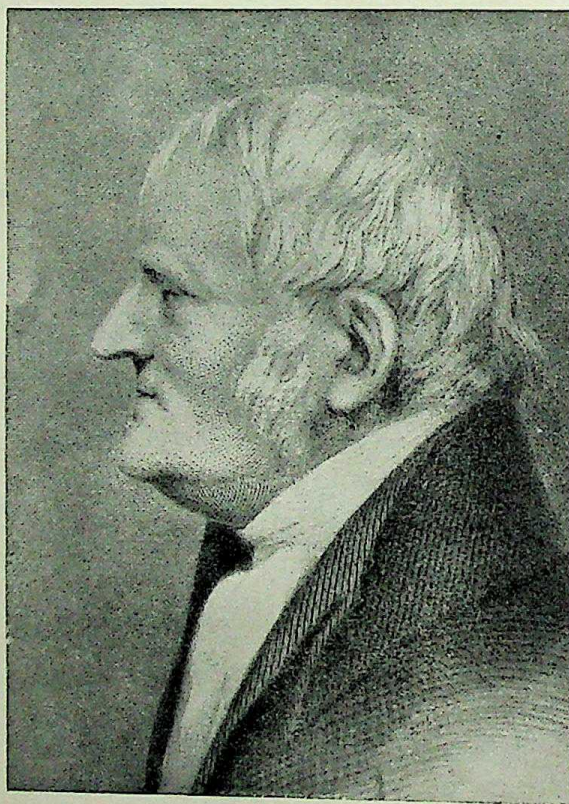
REFERENCES

- [1] LANDSTEINER, K. *The Specificity of Serological Reactions* (Charles C. Thomas, Springfield, Ill., 1936).
- [2] PAULING, L. *J. Am. Chem. Soc.*, **62**, 2643 (1940).
- [3] BREINL, S., and HAUROWITZ, F. *Zeit. physiol. Chem.*, **192**, 45 (1930).
- [4] ALEXANDER, J. *J. Protoplasma*, **14**, 296 (1931).
- [5] MUDD, STUART. *J. Immunol.*, **23**, 423 (1932).
- [6] MARRACK, J. R. 'The Chemistry of Antigens and Antibodies,' Report No. 230 of the Medical Research Council (2nd ed., 1938) (H.M. Stationery Office, London, 1934).
- [7] PRESSMAN, D., GROSSBERG, A. L., PENCE, L. H., and PAULING, L. *J. Am. Chem. Soc.*, **68**, 250 (1946).
- [8] PRESSMAN, D., BRYDEN, J., and PAULING, L. *J. Am. Chem. Soc.* (to appear shortly).
- [9] HEIDELBERGER, M., and KENDALL, F. E. *J. Exp. Med.*, **61**, 559, 563; **62**, 467, 697 (1935).
- [10] PAULING, L., PRESSMAN, D., and CAMPBELL, D. H. *J. Am. Chem. Soc.*, **66**, 330 (1944).
- [11] LANDSTEINER, K., and VAN DER SCHEER, J. *Proc. Soc. Exp. Biol. Med.*, **29**, 747 (1932).
- [12] PAULING, L., PRESSMAN, D., CAMPBELL, D. H., and collaborators. *J. Am. Chem. Soc.*, **64**, 2994, 3015 (1942); **65**, 728 (1943).
- [13] TYLER, A. *Proc. Nat. Acad. Sci.*, **25**, 317 (1939); **26**, 249 (1940); *Growth*, **10** (supplement), 7 (1947).

The belief that matter consists of atoms had been debated by philosophers from the days of Empedocles. Dalton gave the theory precise formulation and applied it to chemical problems. His theory enabled him to explain all the laws of chemical combination then known, and it is a tribute to his genius that, although much modified and extended, his atomic theory is still the foundation of the whole of chemistry. Professor Partington suggests that Dalton was led to his discoveries by his prolonged study of the constitution of the atmosphere.

John Dalton was born at Eaglesfield, a village near Cockermouth in Cumberland, remote from the main centres of commerce and learning. His parents and ancestors were artisans, not peasants, and although the parents were in modest circumstances they had a small

estate: they were 'statesmen' in local speech. They belonged to the Society of Friends, of which body John Dalton was a member throughout his life, and in consequence there is no record of his birth in the parish registers, the date (6th September, 1766) being recalled long afterwards in the memories of neighbours of his parents. His father, a wool-weaver, taught him arithmetic; at the age of 10 he was given lessons in mathematics by Elihu Robinson, a wealthy Quaker of scientific attainments, and also attended a school, where he had the reputation of being steady and persevering but not brilliant. At the age of 12 he himself set up a school, but had difficulty in controlling boys older and bigger than himself. In 1781 he and his brother went as assistants in a school at Kendal, which they took over for themselves in 1785, teaching Greek, Latin, French, and mathematics as well as English subjects. The languages and mathematics were acquired by John as a result



John Dalton, 1766-1844.

of hard study, in which he was encouraged and helped by John Gough, a blind Quaker of exceptional gifts. In the winters of 1787 and 1791 Dalton gave courses of lectures on natural philosophy, including chemistry. His knowledge

of chemistry was acquired from the works of Boerhaave and Boyle, and the *Essays* of Bishop Watson. While at Kendal he had probably studied Newton's *Principia* with Gough. In 1793 he was appointed, on Gough's recommendation, as tutor in mathematics and natural philosophy in New College, Manchester, a Dissenting institution in Mosley Street, which was the outcome of the Warrington Academy. He also taught chemistry, using Lavoisier's *Elements of Chemistry*. Dalton remained in Manchester for the rest of his life; when New College moved he supported himself by private tuition, giving lessons in grammar, arithmetic, and science

for a fee of 1s. an hour, later raised to 1s. 6d. One of his pupils was Joule. He published *Elements of English Grammar: or a New System of Grammatical Instruction* in 1801. In 1824 he gave some lectures to medical students.

Dalton's discovery in 1792 of colour-blindness in himself was announced in 1794, and there are

some amusing anecdotes of the results of this defect of vision. He joined the Manchester Literary and Philosophical Society in 1794, became vice-president in 1808, and was president from 1817 to 1844. He read over a hundred papers to the society, in the rooms of which many relics of Dalton were preserved until their destruction by fire, an indirect result of German incendiary bombs, in 1940. He dressed well but plainly, and had regular habits, on one day of the week playing bowls. His health was good until a few years before his death, and he was a sturdy mountain climber, easily outstripping most of his companions. He never married, saying that he had no time, but he was fond of the society of educated women. Although much in request as a lecturer, he was somewhat uncouth, with a harsh deep voice, and once gave offence by calling the chemical elements 'articles,' as though, it was said, he was a grocer and not a 'natural philosopher.' As an experimenter he was lacking in accuracy; his apparatus, consisting of penny ink-bottles, bits of tubing, and the like, would seem contemptible to many, but he was not often misled by the results. In the difficult department of gas analysis he had unusual skill.

Dalton was somewhat above middle height, with a robust and muscular frame and a slight stoop. His face had some resemblance to Newton's, especially in later life. In 1833 a subscription of £2,000 was raised in Manchester for a marble statue by Chantry, now in the Town Hall, where there is also a fresco by Ford Madox Brown showing Dalton collecting marsh gas from a pond. There is a marble bust by Cardwell in the University library.

Before Dalton had become well known, he lectured, at Davy's invitation, at the Royal Institution, London, in 1803-4, and again in 1809-10, receiving some instruction in the art of lecturing from his brilliant colleague. When he delivered some lectures in Edinburgh his audience was scanty, but in Glasgow in 1807 he had a very good reception. Dalton became F.R.S. in 1822 and received the Royal Medal in 1826; he was elected one of the eight foreign associates of the French Academy in 1830, became D.C.L. of Oxford in 1834, and in 1833, after representations to the Government by Mr. Babbage, was granted a civil pension, which was increased in 1836 to £300 a year. On 27th July, 1844, he died from a stroke, and was given an impressive public funeral. Honours, therefore, were freely bestowed on Dalton during his life, and

he enjoyed the esteem of the whole scientific world.

From his early days Dalton kept a meteorological diary, and made daily entries in this until the morning of his death, his last act being to inscribe 'little rain this,' adding feebly 'day,' so ending his life in a scientific observation. His book *Meteorological Observations and Essays*, published in 1793, a second edition appearing in 1834, contains the germ of his later discoveries, which seem to have begun with a consideration of the state of water vapour in the atmosphere. Newton, in the *Principia*, had adopted the idea that the pressure of air was due to repulsion of the particles by a force varying inversely as the distance. The kinetic explanation that it was due to bombardment by moving particles, given by Bernoulli in 1737, had not been taken up. The atomic theory, from the time of its enunciation in ancient Greece, had never been lost sight of, and Newton, in his *Opticks*, had made extensive use of it. He seems almost to have suspected that different atoms might have different masses, and he certainly assumed that they had different sizes and shapes; the question as to whether they were divisible, he said, could be settled only by experiment.

Lavoisier had used the idea of atoms, and in his *Elements of Chemistry* (1789) he taught that a gas consists of small particles, between which there are particles or 'molecules' of the fluid of heat (caloric), the repulsion of which keeps the gas molecules apart and gives rise to pressure. Lavoisier had shown that the atmosphere contains two gases, oxygen and nitrogen, as well as water vapour, while Newton assumed that air contained one kind of particle only. Some thought the atmosphere was a chemical compound, so explaining why its composition was constant, and why the heavier oxygen did not separate from the nitrogen. The state of the water vapour was undecided. It was the prolonged and persistent study of the problem of the constitution of the atmosphere which led Dalton to the chemical atomic theory.

In 1793, in his *Meteorological Observations and Essays*, he asserted that pure air is 'an intimate mixture of various elastic fluids or gases,' and that 'if we adopt the opinion, which to me seems the more probable, that water evaporated is not chymically combined with the aerial fluids, but exists as a peculiar fluid diffused amongst the rest,' the phenomena of rain and dew are easily explained. A paper in *Nicholson's Journal* in 1801 on 'A New Theory of the Constitution of Mixed

Aeriform Fluids and particularly of the Atmosphere' was extended by four essays, read in 1801 to the Manchester Literary and Philosophical Society, which gave Dalton a European reputation; they contain his 'law of mixed gases,' or law of partial pressures, which he says in his *New System* (1808) was 'hit upon' in the autumn of 1801. This law was equivalent to the assumption that, as Henry said in 1804, in a mixture of gases, each gas 'is a vacuum to every other gas.' In speculating how this could be reconciled with mutually repelling particles of different gases, Dalton seems to have arrived at the view that the particles of different gases have different weights. He made much use of diagrams, some reproduced in his book, showing the 'ultimate particles' of gases as small spheres, surrounded by atmospheres of caloric. In his lectures he also used cubical wooden blocks to represent atoms, and a student's definition of atoms as 'small blocks of wood, painted in different colours, invented by Dr Dalton,' was based on these visual aids to memory. Dalton also used wooden balls with holes to be connected by pins.

The earliest entry in Dalton's notebook giving a table of atomic weights is dated 6th September (his birthday), 1803; the values (hydrogen 1, oxygen 5.66, azote 4, carbon 4.5, etc.) are mostly based on Lavoisier's analyses. The first announcement of the subject is at the end of a paper read on 12th November, 1802, to the Philosophical Society, but first printed in 1805, describing some experiments on mixing air and nitric oxide over water; these first appear in Dalton's notebook in the period October–November 1803, and were added after the paper was read. They showed 'that oxygen may combine with a certain portion of nitrous gas or with twice that portion, but with no intermediate quantities.' In a footnote in the printed paper he says: 'An enquiry into the relative weights of the ultimate particles of bodies is a subject, as far as I know, entirely new: I have recently been prosecuting this enquiry with remarkable success. The principle cannot be entered upon in this paper; but I shall just subjoin the results, as far as they appear to be ascertained by my experiments.' Then follows a table of 'relative weights of the ultimate particles of gaseous and other bodies,' the first table of atomic weights, every entry in which (except the standard, hydrogen = 1) is incorrect.

In 1804 Thomas Thomson visited Dalton in Manchester, and in 1807 he gave the earliest detailed account of Dalton's atomic theory in the

third volume of the third edition of his *System of Chemistry*, the first volume of Dalton's own *New System of Chemical Philosophy* not appearing until 1808, and containing only a short section on the theory. In his *History of Chemistry* (1830–1), Thomson gave the origin of Dalton's theory in his detection of multiple proportions in analyses of marsh gas and ethylene by explosion with oxygen, but the theory was in existence at least a year, and probably longer, before these analyses were made to confirm it. It arose from speculations on mixed gases, made with the object of reconciling Newton's theory of the atmosphere (assuming it to be an element) with the new knowledge that it is a mixture of two permanent gases and water vapour.

Dalton's estimates of atomic weights were based on some empirical rules, the first of which was that if only one compound of two elements is known its 'compound atom' contains one atom of each element, 'unless some cause appear to the contrary'; this was based on the idea of the repulsion of atoms of the same kind. The particles of oxygen, nitrogen, etc., were assumed to be atoms, not molecules composed of two atoms. Dalton did not accept Avogadro's hypothesis and doubted the accuracy of Gay-Lussac's law of volumes.

Although his own circular symbols were very inconvenient, Dalton never adopted Berzelius's symbols (which are still in use), saying, in fact, that they were 'horridifying.' His great conservatism was also shown in his refusal to accept Davy's views of the composition of the alkalis, earths, and chlorine. Some papers declined by the Royal Society he issued in book form in 1840–2, with a preface which shows that he felt this action keenly; they contain some important observations and should have been published. Joule's work was rejected by the Royal Society about the same time.

The atomic theory had been known from the time of the Greek philosophers, and some applications of it to physical problems had been made before Dalton. His contribution lay in adapting it to the needs of chemistry by attributing different weights to the atoms of the different chemical elements, and, by assuming combining ratios between the atoms which seemed to him probable, making it possible to calculate the relative weights of atoms from the combining ratios of masses. These results at once explained all the known laws of chemical combination. The later extensions of the theory have broadened and deepened its content, but in its main outlines it still remains Dalton's atomic theory.

The polarization microscope

B. K. JOHNSON

Although the polarization microscope has been used for many years in geological and mineralogical investigations, its potential value in the metallurgical, biological, and chemical fields is perhaps not yet fully appreciated. In this article the fundamental principles involved in the use of the polarization microscope are described, and examples are given of the way in which it can be applied to practical problems, especially in these new fields.

The use of polarized light in conjunction with the microscope has been the means of adding considerably to the usefulness of this instrument for particular branches of science. Among these, perhaps geology must have the first claim, for Sorby's original work in this connection dates back to 1860. Much valuable work has been done with the polarization microscope since that time, and in more recent years it has become of service to workers in the fields of biology and metallurgy.

The appearances of certain kinds of objects when viewed through the polarization microscope considerably assist the microscopist in the identification of a specimen, and this in a manner not possible by ordinary observation with unpolarized light. For instance, the identification of minute particles of crystals, minerals, etc., can be effected by this means; in biological specimens differentiation of fibrous membranes in other tissue may be greatly facilitated; and in metallurgical specimens inclusions may sometimes be identified and stress effects observed.

Before dealing with the polarization microscope itself, a few remarks must be made on polarization phenomena in general—without, however, going into a lengthy treatment of the subject.

Plane-polarized light may be produced:

1. By reflection at a polished surface at the appropriate angle.
2. By transmission through a Nicol prism or modification of this form of prism.
3. By transmission through a plate of tourmaline cut parallel to the optic axis.
4. By transmission through plates of Polaroid (a compound of iodine and quinine sulphate crystallizing in the form of thin, flat plates).

If two polarizing devices are arranged in optical train and so orientated that the vibration directions of light transmitted by them are parallel, light will pass to an eye placed behind the second polarizer (sometimes called the analyser). If, how-

ever, one of them be rotated so that its plane of vibration is now at right angles to that of the other, no light will pass to the eye. The latter condition is frequently spoken of as 'crossed Nicols' and the former as 'parallel Nicols.'

If we place between crossed Nicols certain specimens such as a sheet of glass, quartz, Cellophane, or selenite (i.e. calcium sulphate) and rotate them in their own plane perpendicular to the direction of vision, we find that as the rotation continues they behave differently with respect to the transmission of light. For instance, the glass (provided it is homogeneous and free from strain) will have no effect on the dark field given by the crossed Nicols; the quartz, however, will appear alternately dark and light at each 45° of rotation (see figure 10a and b); the piece of Cellophane (if thin and of uniform thickness) will appear coloured; and the thin plate of selenite (which usually cleaves in layers of varying thickness) will give a multi-coloured appearance when placed at 45° between the crossed Nicols. This effect is illustrated in figure 1.

The effects seen with the last three materials mentioned are due to their bi-refracting nature. The well-known property of double refraction of certain media may be demonstrated by Huygens' early experiments, in which a rhomb of Iceland spar (calcite) is placed over some print, when two images will be seen instead of a single image (figure 12). In a second experiment (figure 13) an illuminated slit may be viewed through a polished crystal of quartz, when two spectra will be seen; if then a polarizing device is placed in turn in each of the beams, it will be found that each beam is itself plane-polarized but that their vibration-directions are mutually perpendicular. A further important point we may learn from this experiment is that as the two beams are deviated by different amounts, the refractive index of the material for the two beams must be different;

hence the two beams travel with different velocities through the medium.

We may thus arrive at the following fundamental conclusion, namely that if a beam of light enters a bi-refracting material it is split up into two beams, vibrating at right angles to each other and travelling with different velocities through the material.

This helps us to understand many of the polarization phenomena we observe. For instance, the colour of a thin plane-parallel plate of some bi-refracting substance when placed at 45° between crossed Nicols and illuminated by white light is due to the fact that the two beams travelling with different velocities through the plate get out of step or out of phase by half a wavelength of one colour of the spectrum; hence this colour is eliminated by interference, and the final appearance of the specimen is white minus that portion eliminated.

Such explanations are, however, not fully adequate, and the matter can be better understood only by a much closer study of polarization phenomena generally. The reader will do well to consult the references given [1, 2, 3, 4], as the limited space in an article of this size does not permit detailed explanations.

The advantage of using polarized light in various branches of work is clearly illustrated by comparing the coloured photomicrographs of figures 1, 2, and 3 with the corresponding appearances in unpolarized light.

Turning now to the accessories required for converting an ordinary microscope into a polarization microscope, it is sufficient in the case of simpler instruments to employ two polarizing devices, one mounted immediately in front of the substage condenser and the other conveniently arranged over the top of the eyepiece but capable of being swung out of position when desired. Both polarizer and analyser are arranged to rotate about the microscope axis, as is also the stage on which the specimen rests. In more advanced instruments mechanical modifications are made in order to permit the introduction of certain optical devices for carrying out particular tests on the specimens. For instance, provision must be made in the side of the body-tube for inserting such things as a retardation wedge, a wave-plate, and a Bertrand lens, the purposes of which are described later. The optical system, therefore, for a polarization microscope becomes as depicted in figure 14. P is the polarizer (usually a Nicol prism) situated immediately beneath the con-

denser C; it can be rotated about a vertical axis. S is the rotating stage on which the specimen is placed, O the microscope objective, E the eyepiece, and A the analyser, which may consist of a small Nicol prism, a plate of tourmaline, or a Polaroid plate. The named optical parts on the right of the figure are some of the required auxiliary devices, and the positions at which they slide into the body-tube are indicated.

MEASUREMENT OF BI-REFRINGENCE

One of the more important measurements which can be made with the polarization microscope is the numerical determination of the bi-refringence of a minute piece of a specimen, for this is frequently the keynote to its identification.

The difference in the refractive indices ($N_1 - N_2$) of the material for the two beams is known as its bi-refringence; and as substances are often tabulated in order of their bi-refracting power¹ the identification of the specimen is thus rendered possible.

The determination is effected by a measurement of the retardation R of one beam with respect to the other as they pass through a plate of the substance, and by a measurement of its thickness t . The bi-refringence ($N_1 - N_2$) is equal to R/t .

The measurement of the retardation R is carried out by an optical device known as a retardation wedge, which consists of a thin wedge of some uniaxial bi-refracting material (e.g. quartz) cut with its surfaces parallel to the optical axis (see figure 11). If such a wedge is placed between crossed Nicols, inclined at 45° to the vibration-direction of the polarizer and illuminated by monochromatic light, dark interference bands will be seen at positions along the wedge where the thicknesses are such that the retardation between the two beams (set up by the bi-refracting nature of the quartz) is a half-wavelength, or an odd multiple of a half-wavelength, of the monochromatic light used. For example, figure 5 shows such a wedge illuminated by monochromatic red light ($\lambda = 6,200 \text{ \AA}$); the interference bands and their relative positions on the scale can be seen.

If, however, the wedge is illuminated by white light instead of monochromatic light, a series of interference colours is seen, each colour corresponding to a particular retardation. Figure 4 illustrates these 'order of polarization colours' as they are called. Starting from black, when the thickness of the wedge is zero, bluish-grey tints

¹ *Manual of Petrographic Methods*, p. 373, ref. 5.

48
is.
is
ve-
of
a
he
ix-
de

ts
ro-
bi-
for
n.
—
vn
en
er¹
ed

re-
ct
he
t.

is
a
ge
(z)
is
en
n-
oy
ds
re
e-
g
an
o-
vs
ed
d
oe

te
of
e-
4
as
ne
ts
—

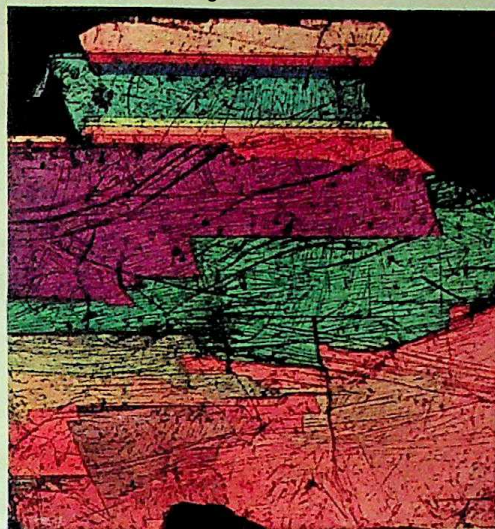


FIGURE 1 - A cleavage plate of selenite as seen (left) with unpolarized light and (right) when viewed in polarized light.

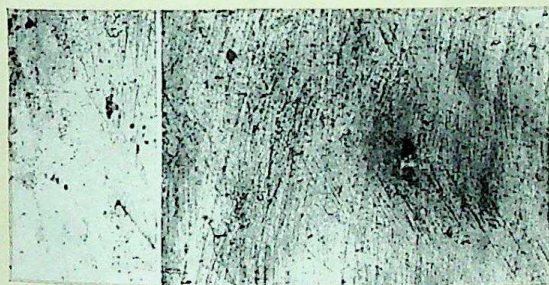


FIGURE 2 - Photomicrographs of a thin section of natural horn taken in (left) unpolarized light and (right) polarized light. The same part of the object has been photographed in each case.

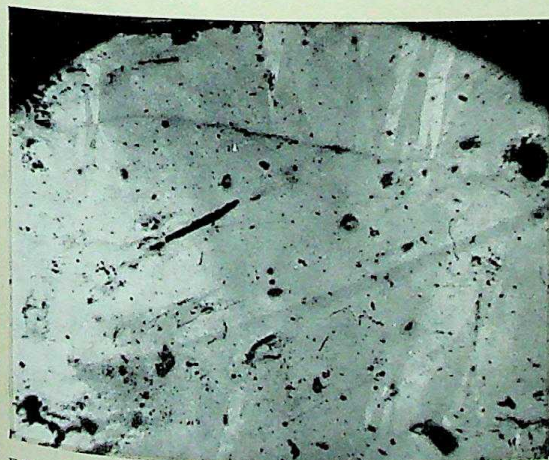


FIGURE 3 - Photomicrographs of an opaque object (namely copper sulphide) taken in (left) unpolarized light and (right) polarized light. The same part of the specimen has been photographed in each case.

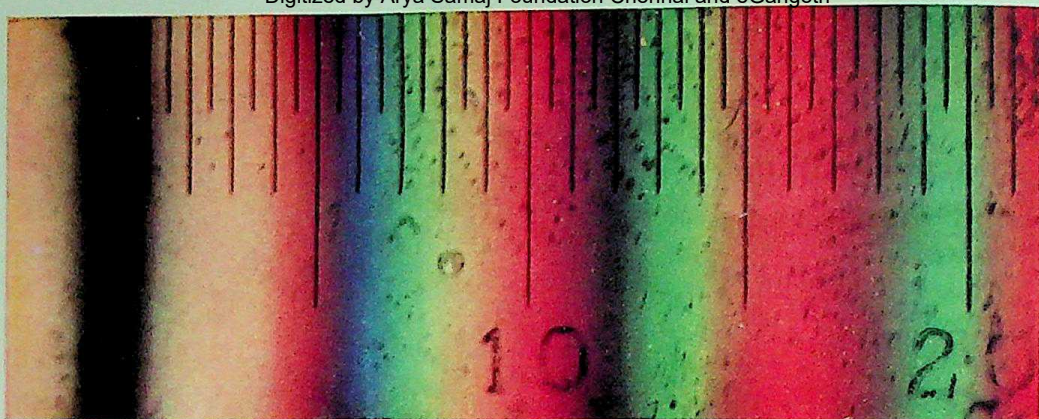


FIGURE 4 - Order of polarization colours. The calibrated scale superposed on the colours aids in determining the retardation from the colour (e.g. scale reading 10 corresponds to 1 micron retardation).

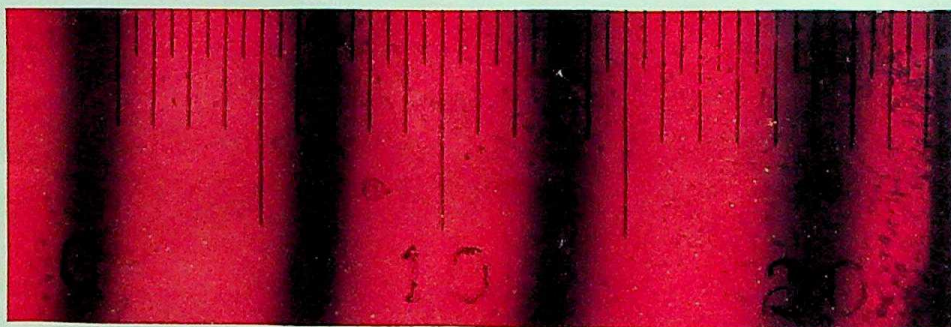


FIGURE 5 - Interference bands seen when a retardation wedge is illuminated by monochromatic light.

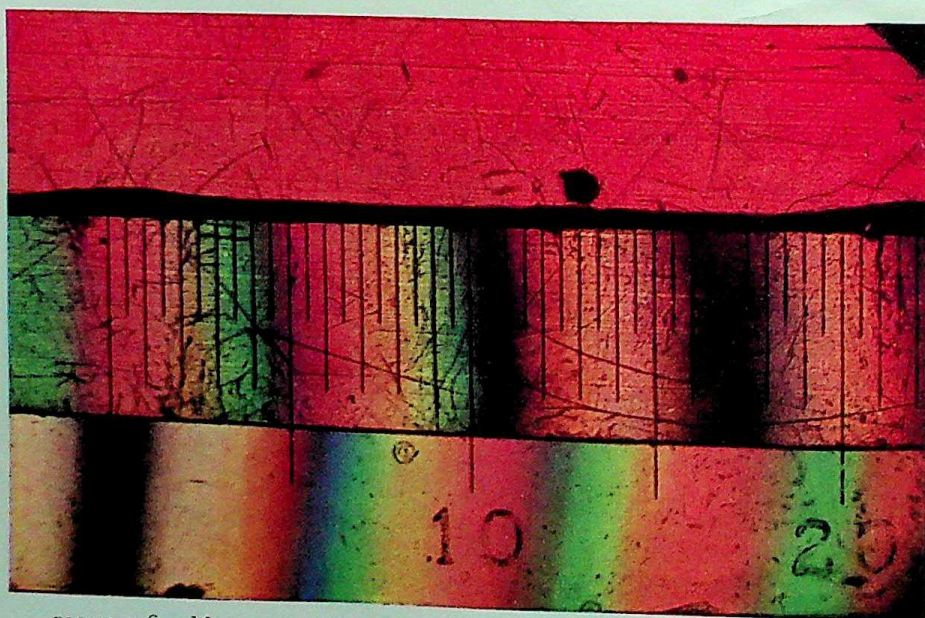


FIGURE 6 - Measurement of retardation by superposing images of specimens to wedge.

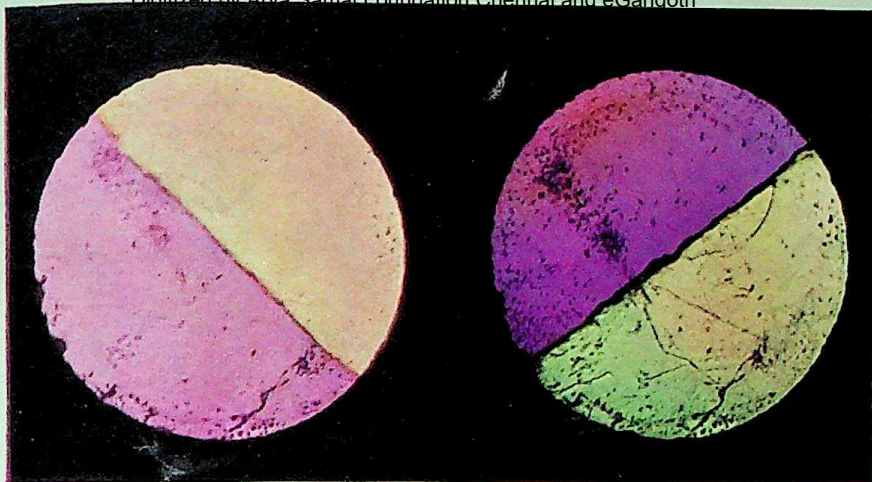


FIGURE 7 - Measurement of retardation by means of a wave-plate.

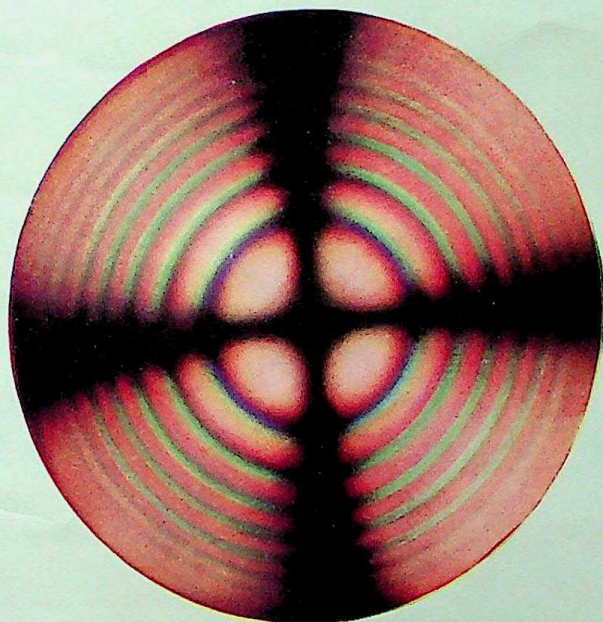


FIGURE 8 - Characteristic ring and brush figure given by a uniaxial crystal seen in convergent polarized light.

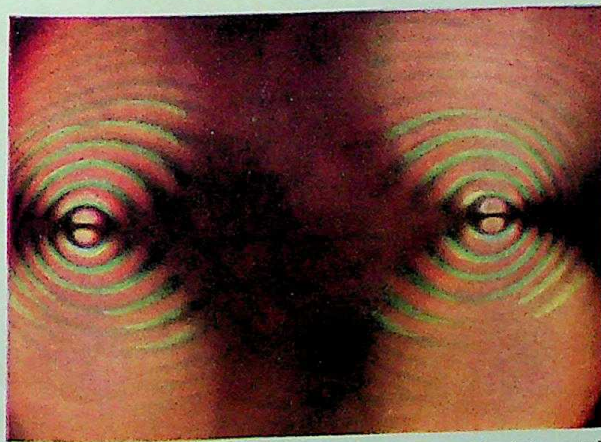
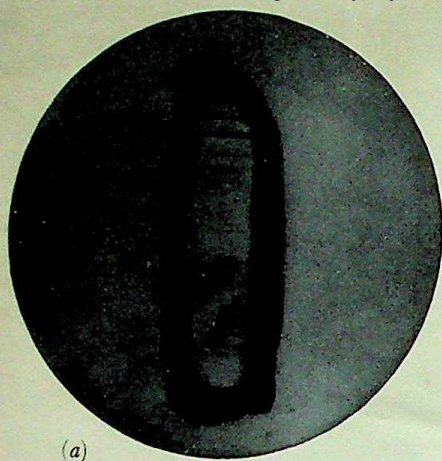
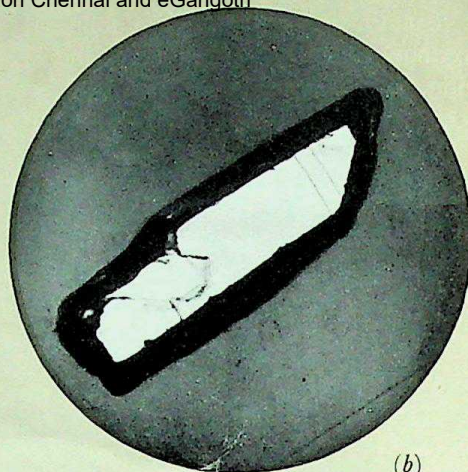


FIGURE 9 - 'Two eye' appearance given by a biaxial crystal viewed in convergent polarized light.



(a)



(b)

FIGURE 10 - A small quartz crystal as seen between crossed Nicols, (left) when placed parallel to the vibration direction of the polarizer, (right) when placed at 45° to the vibration direction of the polarizer.

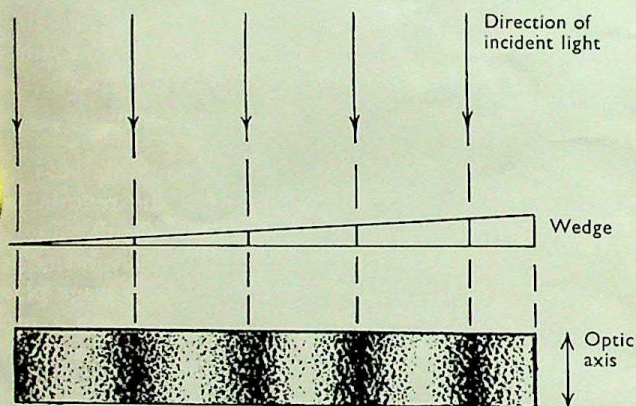


FIGURE 11 - Diagrammatic representation of the effect of a wedge consisting of some uniaxial bi-refracting material such as quartz. Bands are formed when the thickness of the wedge is such that the retardation between the two beams is a half-wavelength, or an odd multiple of a half-wavelength.



FIGURE 12 - Double refraction produced by a rhomb of calcite.

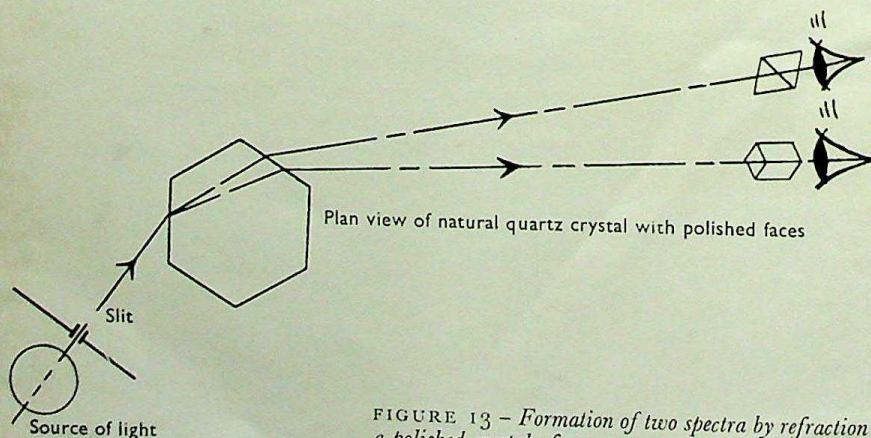


FIGURE 13 - Formation of two spectra by refraction through a polished crystal of quartz.

are the first to appear; they are followed by yellow, orange, red, etc., for positions of increasing retardation. A study of the order of appearance of these colours for known retardations has been made by Quincke. His table is given below:

TABLE OF POLARIZATION COLOURS

Retardation in Microns for $\lambda = 5,893 \text{ \AA}$	Interference Colours between Crossed Nicols	Order
0.00	Black	FIRST
0.04	Iron-grey	
0.097	Lavender-grey	
0.158	Greyish blue	
0.218	Clearer grey	
0.234	Greenish white	
0.259	White	
0.267	Yellowish white	
0.281	Straw-yellow	
0.306	Light yellow	
0.332	Bright yellow	
0.430	Brownish yellow	
0.505	Reddish orange	
0.536	Red	
0.551	Deep red	
0.565	Purple	SECOND
0.575	Violet	
0.589	Indigo	
0.664	Blue (sky-blue)	
0.728	Greenish blue	
0.826	Light green	
0.850	Yellow-green	
0.910	Yellow	
0.948	Orange	
1.101	Violet-red	
1.128	Bluish violet	THIRD
1.151	Indigo	
1.258	Greenish blue	
1.334	Sea-green	
1.426	Greenish yellow	
1.495	Flesh colour	
1.534	Carmine	
1.621	Dull purple	
1.652	Violet-grey	FOURTH
1.682	Greyish blue	
1.711	Dull sea-green	
1.744	Bluish green	

Obviously, then, the colour of a specimen seen in polarized light is a valuable indication of the relative retardation, but it might be difficult (except with long experience) to recognize with certainty any one of the many tints given in the above table if it were seen by itself in the microscope. Here lies the importance of being able to

insert a retardation wedge into the microscope, for if the coloured image of the specimen and the colours of the wedge are seen simultaneously in the field, the possibility of matching the colour will be apparent. For example, figure 6 shows (at the top) a specimen of a colour which might be described as pink, and by comparing this with the polarization colours given by the wedge (at the bottom of figure 6) we might say that the matching colour was that corresponding to the third order carmine of Quincke's table and having, therefore, a retardation of 1.53 microns. This may be further verified by superposing the image of the specimen over half the wedge, as shown in the centre strip of figure 6, where it will be noticed that the black band at zero retardation has moved along until it is now opposite the previously presumed matching colour, thus proving that this is the correct retardation measurement for the specimen under test. It is then necessary only to measure the thickness of the specimen (which may be carried out either by micrometer screw gauge or depth gauge or by the microscope method), and the bi-refringence can be determined from the relation given earlier.

Another method of measuring retardation is to employ a wave-plate instead of the retardation wedge. The latter is obviously a difficult thing to make, whereas the former is comparatively simple. A wave-plate usually consists of a cleavage plate of mica, of such a thinness that it shows a pronounced and definite polarization colour approximately near the central range of retardations given in the table. In the experiment illustrated in figure 7, the writer has chosen a wave-plate which shows a second order purple colour (retardation 0.565) when placed at 45° between crossed Nicols; if then the image of the specimen is superposed half over the colour of the wave-plate, and if it is rotated on the microscope stage until maximum brightness is secured, then a certain colour (in this case straw-yellow) will be seen. If the specimen is now rotated through 90° we find a yellow-green coloration over that half of the field. By referring to the table it will be noted that in one case the colour has moved down the polarization scale, namely to a retardation value of 0.281, while in the other case a rise in order of colours has occurred (viz. to a retardation value of 0.850). Using the retardation of the wave-plate (i.e. 0.565) as the reference point, we see that the amount the one colour has dropped in the scale (0.565 — 0.281) is the same as the amount the other colour has risen in the scale (0.850 —

0.565). The actual retardation produced by the specimen is thus 0.284 microns.

CONVERGENT POLARIZED LIGHT

In geological work, the use of so-called convergent polarized light is a convenient means of differentiating between uniaxial and biaxial crystals. The respective characteristic appearances seen are shown in figures 8 and 9, but a detailed explanation of these would occupy more space than is here available. For the reader requiring a fuller understanding of these physical phenomena, a closer study will be found in the references already given [1, 2, 4].

When examining crystal sections by convergent light in the polarization microscope, the effective

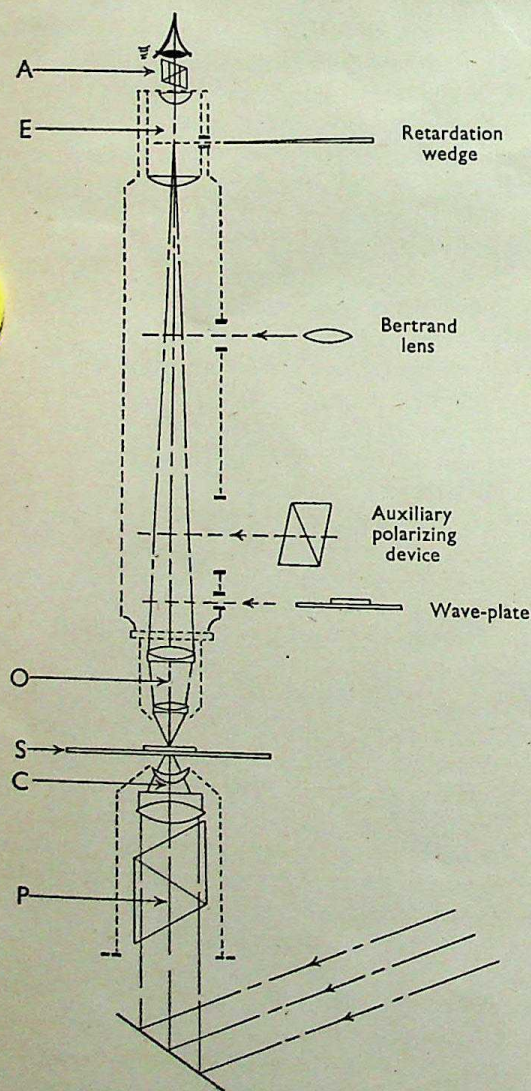


FIGURE 14 - Optical system of a polarization microscope.

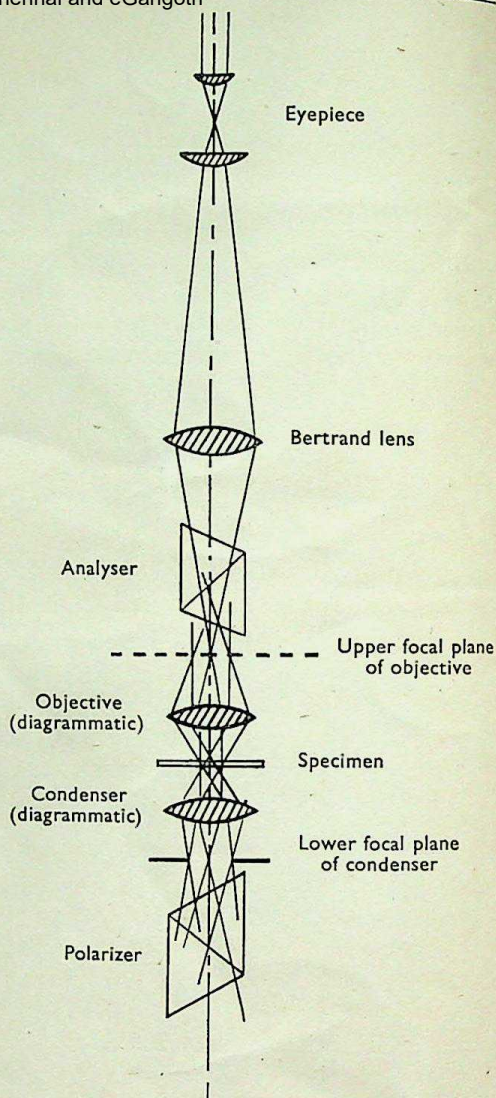


FIGURE 15 - Arrangement of optical parts for observation in so-called convergent light (diagrammatic only).

light (already polarized) may be looked upon as originating at points in the lower focal plane of the substage condenser (see figure 15). This light passes through the specimen under observation in parallel bundles at different inclinations to the axis of the microscope; they are brought to a focus in the upper focal plane of the objective, where the polarization effects can be examined. For this purpose an auxiliary lens, known as a Bertrand lens, is introduced into the microscope tube at the position indicated in the diagram (figure 15), which, together with the eyepiece, produces a low-power microscope system for observation of the upper focal plane of the

objective. This will be clear from the ray diagram given in the figure, as will also the passage of parallel bundles of differently inclined rays through the specimen. It will be noted that the term 'convergent light' really refers to converging bundles of sets of (polarized) rays passing through the object rather than to a highly convergent cone of rays as might at first be interpreted.

With the microscope arranged in this way, it is possible to observe the interference effects produced by the specimen, giving either the 'ring and brush' figure characteristic of a uniaxial crystal or the 'two eyes' appearance of a biaxial.

OPTICAL ROTATION

If a thin plate of quartz be cut with its faces perpendicular to the optical axis and then placed between crossed Nicols in monochromatic light, light is transmitted by the analyser; but on rotating the latter a position will be found where the light is extinguished. It follows, therefore, that the light leaving the quartz plate is plane-polarized, and that the plane in which the vibrations are taking place has been rotated. This phenomenon, which was discovered by Arago in the early nineteenth century and was later fully investigated by Biot, is known as optical rotation. It occurs not only with quartz but with many other crystals and a number of liquids, such as turpentine, nicotine, solutions of sugar, etc.

With a given substance the angle through which the plane of vibration is rotated is proportional to the thickness of the plate;¹ and with a given thickness of material this angle of rotation is inversely proportional to the square of the wavelength of the light employed. In the case of an optically active solution, the rotation for a given thickness of solution is very closely proportional to the weight of the active material dissolved in unit volume of the solution.

These principles have been applied in industrial and other branches of work in the form of

¹ E.g. the rotation of the plane of polarization produced by a plate of quartz 1 mm thick is 21.7° for light of wavelength 5,893 Å (i.e. the sodium line).

polarimeters and saccharimeters, but they may be used also in connection with the polarization microscope. For instance, if the instrument is arranged as in figure 15, but with no object on the stage and with the Nicols parallel, a circular image of the substage iris will be seen in the upper focal plane of the objective. The Nicols are then crossed (giving a dark field), and a reading from the angular scale attached to the polarizer may be taken.² If now a piece of, say, axis-cut quartz is placed on the microscope stage, the field will appear illuminated but may be restored to darkness by further rotation of the polarizer. By thus determining the angular rotation produced, and by measurement of the thickness of the specimen, the rotation per millimetre may be calculated; from this information a possible identification of the material may result. These remarks apply also to a liquid contained in a cell of known thickness resting on the microscope stage, although the accuracy in this case will not be particularly great, owing to the smaller angular rotation per millimetre of most optically active fluids, and to the limits in length of the containing cell set by the distance between the microscope objective and the stage. However, such a test may frequently serve as an aid to the identification of a specimen when used in conjunction with the other tests.

In conclusion it will be realized that this article deals only with the general application of polarized light to the microscope, for it is well known that fairly extensive use of the polarization microscope has been made in connection with geology and mineralogy; hitherto it has been less used in the field of biology. Recent work on the X-ray analysis of many organic substances indicates that they have a highly regular arrangement of their constituent molecules and atoms, and behave similarly to bi-refracting materials when examined in polarized light. It follows that a systematic study on these lines (including, for example, the measurement and tabulation of bi-refringence of such substances) might prove extremely fruitful.

² Monochromatic light should be used.

REFERENCES

- [1] FINCHAM, W. H. A. *Optics*, 318-42 (Hatton Press).
- [2] MARTIN, L. C. *Applied Optics*, vol. 1, 187-225 (Pitman).
- [3] JOHNSON, B. K. *Practical Optics*, 131 (Hatton Press).
- [4] *Dictionary of Applied Physics*, vol. iv, 490-511 (Macmillan).
- [5] JOHANNSEN, A. *Manual of Petrographic Methods*, 371, 373 (McGraw-Hill).
- [6] *Proc. Geologists' Assoc.*, 1909, vol. 21 (pt. 2).

The scientific investigator, continually occupied with his own problems, often finds little opportunity to reflect upon the past, present, and future of other fields of work. It is with this thought in mind that the writer has attempted to discuss a few of the striking advances in the domain of structural inorganic chemistry, and to mention some of the unsolved problems. Many fundamental conceptions have had to be abandoned or modified in the light of recent work: even the law of constant composition has not come through unscathed.

Most students of chemistry know that Joseph Louis Proust analysed a wide range of substances and in 1799 summarized his conclusions in the law of constant proportion, which states that the same body is invariably composed of the same elements united in the same proportion. In recent years, however, evidence has gradually accumulated—particularly from crystal chemistry—which goes far towards changing our ideas on this fundamental law of chemical combination.

The law of constant proportion is rigidly obeyed when a substance is made up of molecules such as those of nitrogen, carbon dioxide, hydrogen, etc. It applies, too, in full rigidity to binary ionic compounds such as common salt or calcium carbonate. Essentially this means that the law of constant proportion depends on definite directed electron-sharing bonds, or on the necessary equality of positive and negative ionic charges. Compounds may, however, occur in conformity with the law if the conditions of geometrical packing in the crystal are such that the sizes of the various components are very different and the structure well fitted together. Excellent examples are the alums, which exist, of course, only in the crystalline state. When the different units from which the crystal is built differ slightly in size and shape, they may occupy indifferently the same positions. A simple illustration is the mixed crystal containing potassium chloride and potassium bromide. The cell varies continuously as the composition, but the well-known sodium chloride structure is maintained at all concentrations. There is a random distribution of chlorine and bromine ions in the anion positions. It may be objected that the mixed crystals of composition potassium chloride + potassium bromide are not chemical compounds. Some crystallographers maintain that a chemical compound is a structure in which crystallographically equivalent positions are occupied by chemically identical atoms. In the light of such opinions it is clearly

impossible to give a universally acceptable definition of chemical combination. Provided the structure of a substance is known, it is perhaps of little real importance whether it is designated as a chemical compound or not.

Important groups of substances in which the combining proportions may vary, and the valency laws are only approximately obeyed, are the metal sulphides, arsenides, and antimonides. Reference to chemical literature will show that analysts have assigned to the mineral pyrrhotite formulae ranging from Fe_6S_7 to $\text{Fe}_{11}\text{S}_{12}$. To explain the variable composition, an obvious suggestion is that additional sulphur atoms fit into the interstices of an ideal FeS lattice. This idea cannot be maintained, for crystallographers have shown that there is insufficient space in such a lattice to accommodate sulphur atoms. Two other reasonable explanations suggest themselves. It may be that, in the lattice, sulphur atoms replace iron atoms to a certain extent, or that there are vacant iron positions. That the latter is the true explanation was evident from the work of Hägg and Sücksdorf [1] in 1933. These investigators compared the densities and unit cell measurements of samples of pyrrhotite, and their results are summarized in figure 1, which is taken from their paper. The upper curve indicates the calculated effect on the density of substituting sulphur for iron, while the lower curve shows the calculated effect of withdrawing iron atoms from some of the lattice points. The conclusion is clear. The variation in the composition of pyrrhotite occurs because iron atoms are withdrawn from some of the lattice points. X-ray methods thus solved a problem of profound importance. It is, alas, no longer possible to assure elementary students of chemistry that the stoichiometric compound FeS is formed by heating iron and sulphur together. The term 'defect structure' was proposed in 1936 for such structures, which X-ray investigations have disclosed to be not

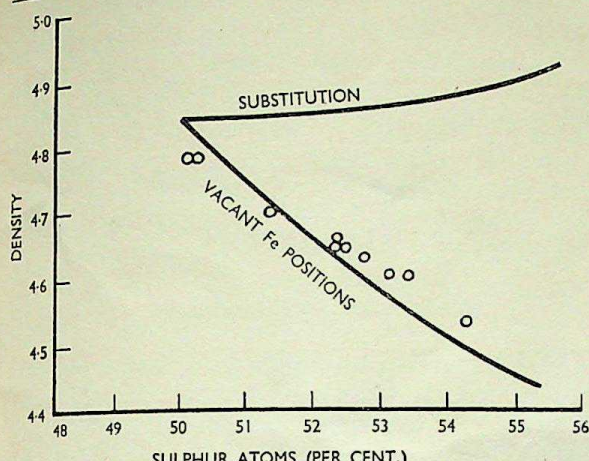


FIGURE 1 - The circles show the observed variation of density with composition.

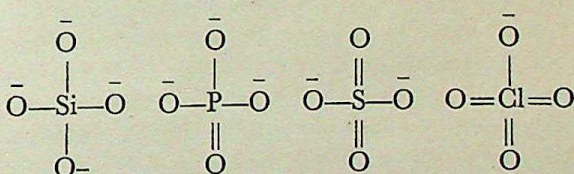
uncommon. In fact, in certain types of compounds they are the rule rather than the exception.

It is reasonable to ask what is the position of the laws of definite and multiple proportions. These laws were formulated at a period when the known chemical compounds were of simpler type. In the light of fuller knowledge it is recognized that the laws are applicable to restricted types of chemical compounds. Many hydrides, phosphides, sulphides, selenides, arsenides, certain oxides and iodides, and some complex compounds are exceptions to the rule [2].

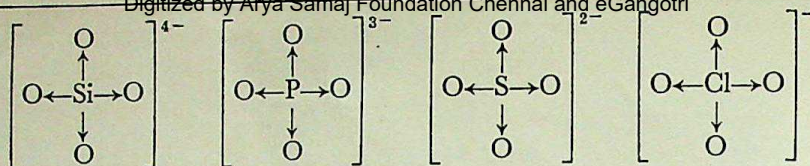
In the realm of inorganic chemistry the study of the arrangement of atoms in solid bodies has enabled chemical problems to be viewed from an entirely new angle. Inorganic chemists at one time postulated a whole series of silicic acids to account for the composition of the mineral silicates. Nowadays it is established that rocks are made up of oxygen atoms cemented together with silicon, aluminium, and a few other metallic atoms. It is well known that the eight common elements—oxygen, silicon, aluminium, iron, magnesium, calcium, sodium, and potassium—account for some 98 per cent. of the earth's solid crust, and the bulk of the crust is oxygen. The distribution of these elements is very interesting. Each silicon atom is surrounded by four oxygen atoms, so that the four oxygens are grouped together at the corners of a tetrahedron and the silicon is situated at the centre. By far the greater part of the aluminium in the earth's crust is distributed similarly to the silicon. Iron, magnesium, and the remainder of the aluminium have a different distribution. Six

oxygens are grouped at the corners of an octahedron with an iron, magnesium, or aluminium atom at the centre. Thus aluminium can play a dual role, generally associating tetrahedrally with oxygen but sometimes behaving like the metals iron and magnesium. Finally, the alkali and alkaline earth ions are accommodated in large, often unsymmetrical, holes in the structure. Potash feldspar, one of the most important rock-forming minerals, has the empirical formula KAlSi_3O_8 . The limitations of such chemical formulae in inorganic chemistry are well illustrated by this special case. The feldspar is actually composed of silicon and aluminium tetrahedra linked by every corner in every direction, and constituting a three-dimensional lattice-work of tetrahedra. Enmeshed in its interstices are the potassium ions. It is an interesting fact that magnesium and iron are never found in the feldspars, and a most convincing explanation of it is available. It is geometrically impossible to fit octahedra into a structure of tetrahedra linked by all their corners. As a consequence, magnesium and iron, which are 6-coordinated with oxygen atoms, are excluded from the feldspar structure.

In dealing with bonds between oxygen and non-metallic elements, the structure of ions of the type XO_4 is of peculiar interest. The classical formulae showed the central atom with the group valency:



Until recently these formulae had fallen into disuse, principally because of the success with which many compounds could be systematized if the valency group of electrons was assumed to be an octet—a suggestion made by G. N. Lewis in 1916. Assuming that a single bond corresponds to the sharing of two electrons, one from each atom, the classical formulae demand that the central atoms, Si, P, S, and Cl, have valency groups of 8, 10, 12, and 14 electrons respectively. On the octet theory, however, an alternative formulation is possible if it is assumed that the two electrons binding each oxygen atom can be provided by the central atom. This type of bond was named the co-ordinate link and given the symbol $\rightarrow$. The atoms Si, P, S, and Cl could then form ions as shown on the following page.



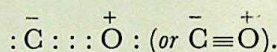
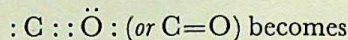
Parachor measurements and stereochemical observations were held to support these formulae. In 1937 L. Pauling and L. O. Brockway [3] pointed out that the bond lengths in the common oxy-acid ions, determined by X-ray analysis of crystals, are much shorter than the single-bond covalent radii for the atoms. The bond lengths in the tetrahedral ions are given below:

	Si—O	P—O	S—O	Cl—O
Observed ..	1.60	1.55	1.51	1.48
Calc. X—O ..	1.83	1.76	1.70	1.65
X=O ..	1.65	1.58	1.53	1.48

What is the significance of this shortening? Pauling interprets the results as indicating that there is a resonance between several possible structures with double bonds holding one or more of the oxygen atoms. In the case of chlorine, the Cl—O distance is that expected for pure double bonds. For formulating these oxy-acid ions Pauling [4] suggests that ordinarily the classical formulae should be used. Obviously the classical formulae are not in entire agreement with the bond distances given in the table. The classical formulae would require resonance between single and double bonds, and the final bond distances should be greater than the value for a double covalent bond. There is evidence, of course, that a co-ordinate link can be shorter than a normal single covalent bond. For example, the N—O distance is 1.43 Å—appreciably larger than the nitrogen-oxygen bond length in $(\text{CH}_3)_3\text{N} \rightarrow \text{O}$, which is 1.36 Å. It is quite evident that at the present time there is no way of formulating these ions which is free from objection.

The structure of carbon monoxide continues to excite interest, although it has long been a debated problem. Earlier chemists regarded the carbon as bivalent in this oxide and supposed the formula $\text{C}=\text{O}$ to be entirely satisfactory. Langmuir in 1919 proposed a new formulation, in which carbon would have its octet of electrons. In the early formula it is clear that the carbon has a sextet of electrons. However, by sharing one of the unshared pairs of oxygen electrons the carbon

completes its octet:



The arguments put forward in favour of this triple-bond structure of Langmuir include considerations of electrical dipole moment, the interatomic distances, force constant, and the molecular orbital theory. For example, Sidgwick [5] emphasized in 1933 that the minute moment of carbon monoxide can be explained only by supposing that the very unequal sharing of electrons between the carbon and the oxygen is offset by the transference of an electron from the oxygen to the carbon. Pauling in 1939 suggested that the CO molecule must be regarded as a resonance hybrid of the forms



He brought forward arguments to support the view that the structures (a), (b), and (c) contribute about equally to the normal state of the molecule. The very small value of the electric dipole moment provides evidence that the contribution made by structure (c) must be about the same as that of structure (a). Structure (b) would have no large dipole moment, whereas those of (a) and (c) are very large. Only if (a) and (c) contribute about equally would the moment of the molecule be small, in accordance with experiment. Recently, however, it has been argued by L. H. Long and A. D. Walsh [6] that it is quite possible to give a molecular orbital description of the carbon monoxide bond that amounts to an approximate double bond. The great stability of carbon monoxide has frequently been used as an argument against formulating it as $\text{C}=\text{O}$. L. H. Long and R. G. W. Norrish [7], in 1946 brought forward a possible reason why CO does not polymerize to $\text{O}=\text{C}=\text{C}=\text{O}$. Their evidence indicates that to excite the CO molecule to a radical with two free valencies would require an excitation energy of more than 75 kcal, and that the energy required to excite two molecules in this manner is greater than the energy normally

associated with a C=C bond. It seems reasonable to conclude that attempts to prepare C_2O_2 have been unsuccessful because this substance is thermodynamically unstable. To sum up, the double-bond formula $C=O$, while not free from objections, is probably the best representation for this molecule at the present time.

Intimately associated with the problem of the constitution of carbon monoxide is the question of the structure of the metallic carbonyls. At one time it seemed that there was a strong case for writing metallic carbonyls as $M \leftarrow \bar{C} \equiv \overset{+}{O}$ or $\bar{M} - C \equiv \overset{+}{O}$. Here the carbon monoxide provides two electrons to form a co-ordinate link with the metallic atom. In an investigation by the electron diffraction method, Brockway and Cross [8] in 1935 found that the nickel-carbon distance was 1.82 Å, whereas the theoretical distance for a double bond is about 1.79 Å. This provides support for the view that the nickel-carbon bonds have a large percentage of double-bond character, and this means that the CO must be represented approximately as $C=O$. However, while the structure of nickel carbonyl in these circumstances is $Ni=C=O$, there is probably resonance, and

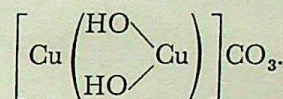
the configuration $-\overset{4-}{Ni} : C :: \overset{+}{O}$ must also be

taken into consideration. Evidence for both these types of bonding is found in the results obtained by an X-ray analysis of the solid $Fe_2(CO)_9$. Powell and Ewens [9] found that three of the CO

groups form bonds $\begin{array}{c} Fe \\ | \\ Fe-C=O, \text{ as in ketones. The} \\ | \\ Fe \end{array}$ C—O distance in these groups is ca. 1.3 Å, comparable with that in ketones and much larger than

that in the six remaining CO groups, which is 1.15 Å. It is suggested that the bonding here is $\bar{Fe}-C \equiv \overset{+}{O}$. On the data from an electron-diffraction investigation the pentacarbonyl $Fe(CO)_5$ is given a trigonal bipyramidal structure [10]. Here the iron-carbon distances of 1.84 Å indicate considerable double-bond character. Finally, the electron-diffraction method applied to the interesting solid carbonyls $Cr(CO)_6$, $Mo(CO)_6$, and $W(CO)_6$ [11], which can be sublimed without decomposition, has indicated that they have a regular octahedral configuration with the metal-carbon distances principally favouring single bonds.

Many of the structural formulae which have been assigned to chemical compounds have in the light of fuller knowledge proved to be quite erroneous. Werner formulated the mineral malachite as



Actually it does not contain a complex ion but consists of a three-dimensional distribution of Cu^{2+} , CO_3^{2-} , and OH^- ions. How dangerous it can be to adopt simple empirical formulae is illustrated by the chloride $CsAuCl_3$. This is not an example of bivalent gold but a complex salt which contains univalent and trivalent gold, with the composition $Cs_2Au'Au'''Cl_6$ [12]. In the solid state phosphorus pentachloride has been shown by X-ray methods to consist of tetrahedral $[PCl_4]^+$ and octahedral $[PCl_6]^-$ ions [13]. A very full determination [14] of the structure of $(NH_4)_3ZnCl_5$ has disclosed that this substance is built up of NH_4^+ , Cl^- , and $[ZnCl_4]^{2-}$ ions, and that the true formula is $(NH_4)_2ZnCl_4 \cdot NH_4Cl$. As in the case of solid phosphorus pentachloride, the fivefold co-ordination has once again been avoided.

REFERENCES

- [1] HÄGG, G., and SÜCKSDORFF, I. *Z. physikal. Chem.*, 1933, B22, 444.
- [2] See ANDERSON, J. S. *Ann. Reports Chem. Soc.*, 1946, 43, 104.
- [3] PAULING, L., and BROCKWAY, L. O. *J. Amer. Chem. Soc.*, 1937, 59, 13.
- [4] PAULING, L. *Nature of the Chemical Bond*, 1940, p. 242.
- [5] SIDGWICK, N. V. *The Covalent Link in Chemistry*, 1933, p. 187.
- [6] LONG, L. H., and WALSH, A. D. *Trans. Faraday Soc.*, 1947, 43, 344.
- [7] LONG, L. H., and NORRISH, R. G. W. *Proc. Roy. Soc. (A)*, 1946, 187, 337.
- [8] BROCKWAY, L. O., and CROSS, P. C. *J. Chem. Phys.*, 1935, 3, 828.
- [9] POWELL, H. M., and EWENS, R. V. G. *J. Chem. Soc.*, 1939, 286.
- [10] EWENS, R. V. G., and LISTER, M. W. *Trans. Faraday Soc.*, 1939, 35, 681.
- [11] BROCKWAY, L. O., EWENS, R. V. G., and LISTER, M. W. *Ibid.*, 1938, 34, 1350.
- [12] ELLIOTT, N., and PAULING, L. *J. Amer. Chem. Soc.*, 1938, 60, 1846.
- [13] POWELL, H. M., CLARK, D., and WELLS, A. F. *J. Chem. Soc.*, 1942, 642.
- [14] KLUG, H. P., and ALEXANDER, L. *J. Amer. Chem. Soc.*, 1944, 66, 1056.

ARTHUR C. CLARKE

Within a generation rocket propulsion has been transformed from the hobby of a few enthusiasts to an accepted field of physical research which has produced results of very great practical importance. In this article Mr Clarke discusses the mathematical basis of rocket propulsion in particular relation to the problem of sending projectiles to great altitudes and—a target which no longer seems impossible of achievement—into space itself.

Although the rocket was invented at least seven hundred years ago, its development as a revolutionary weapon of war and as a high-altitude research instrument is almost entirely a matter of the last twenty years. The first scientific study of the rocket's possibilities was made by the Russian Ziolkovsky at the end of the nineteenth century, but his work was little known outside his own country. The modern era of rocket research may be said to have begun with the American R. H. Goddard (1882–1945) and the Rumanian Hermann Oberth (1894–), whose work put the subject on a secure mathematical basis [1, 2]. Goddard showed that with high-efficiency fuels quite small rockets could attain enormous altitudes, while Oberth investigated the more remote possibility of interplanetary exploration. His work was directly responsible for inspiring German rocket research in the 1920's, and from that research in due course came the numerous rocket weapons developed in the later stages of the recent war. Most of the features of the modern liquid-fuel rocket had been foreseen by Oberth twenty years ago.

The rocket owes its outstanding properties to the fact that it is the simplest, and potentially the most efficient, of all heat engines. There is no obvious limit to the size of rocket motor that can be built—for example, the V2 developed over 600,000 h.p., and much larger units are under investigation. Moreover, since it is a pure reaction device and carries its own fuel and oxidizer, it is quite independent of a surrounding medium. The rocket is thus the only known form of propulsion which will operate in airless space, where it is in fact more efficient than in the atmosphere.

The problem of reaching very high altitudes is essentially a ballistic one, since the rocket may be treated as a mere projectile for most of its flight. For ordinary altitudes and velocities of projection the familiar law $h = v^2/2g$ is applicable (if air resistance is neglected), but this parabolic relation-

ship assumes g to be constant throughout the trajectory of the projectile, whereas when the initial velocity exceeds 3 km/sec, the projectile reaches altitudes where gravity is appreciably weakened. Figure 1 shows the operation of the constant-gravity law, and of the correct law allowing for reduction of g with distance. It will be seen that the altitude curve is rising very rapidly at values of 10 km/sec, and it actually reaches infinity at the 'velocity of escape,' 11.2 km/sec.

So far, the greatest terminal velocities attained by rockets are about 1.5 km/sec, and the maximum altitudes are in the region of 180 km. These results were achieved by V2, a purely military machine, and much better performances will be possible with rockets built specifically for high-altitude research. Details have recently been published of a sounding rocket (*Neptune*) now under construction for the U.S. Navy, and because they show very clearly the main characteristics of such machines the performance curves are reproduced in figure 2.

The rocket burns its fuel (in this case alcohol and liquid oxygen) in 75 seconds, during which time it rises vertically for 60 km and reaches a velocity of 2.5 km/sec. This is sufficient to enable it to coast to a maximum altitude of 400 km, the complete upward flight taking 335 seconds. *Neptune* (which should be in use by the end of 1948) is designed to carry 50 kg of instruments to the 400 km level, but it can also carry loads of a metric ton to 140 km.

The development of such machines opens up quite new fields in scientific research, and notable results have already been obtained with modified V2's by American workers at White Sands, New Mexico. For the first time it has been possible to secure direct readings of temperature and pressure at heights well into the ionosphere, and recently the first spectrograms were obtained of the sun's ultra-violet radiation, which does not penetrate the atmosphere. Techniques have been developed

for transmitting observations continuously to receivers on the ground while the rocket is in flight, and it is now possible to retrieve instruments undamaged after their fall back to earth.

Meteorology, physics, and astronomy—to mention only three sciences—will benefit greatly when regular programmes of rocket sounding begin. Quite apart from this, it must be confessed that such research has an excitement—one might even say a glamour—which is met elsewhere only in the

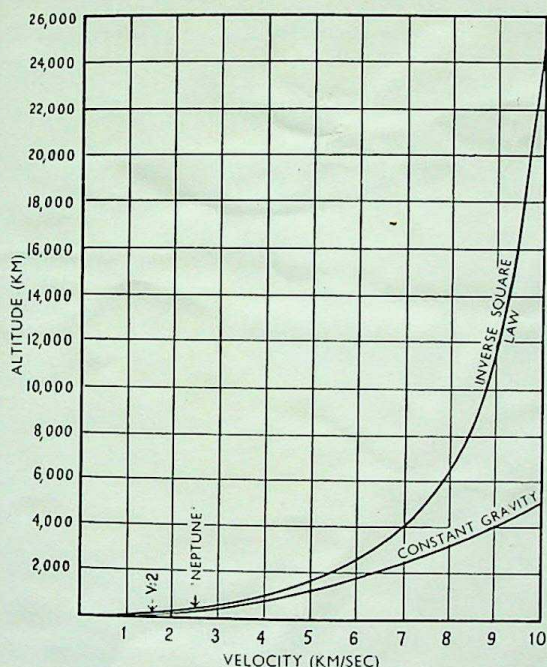


FIGURE 1 - Relationship between velocity of projection and altitude, (a) assuming that the gravitational field is constant, (b) assuming the reduction of the gravitational field according to the inverse square law.

more spectacular branches of atomic physics. The high-altitude rocket has given us our first real freedom of movement in three dimensions, even if at the moment that freedom is by proxy only.

The velocity reached by a rocket—and hence its performance—is determined by two factors: (1) the velocity of the jet or exhaust, and (2) the mass-ratio, which is the ratio between the rocket's initial weight and its final weight after combustion of fuel. If v is the jet velocity and R the mass-ratio, then in the absence of any other forces the final velocity attained by the rocket is given by the equation:

$$V = v \log_e R.$$

However, for a rocket fired vertically from the earth, gravity and air resistance come into play,

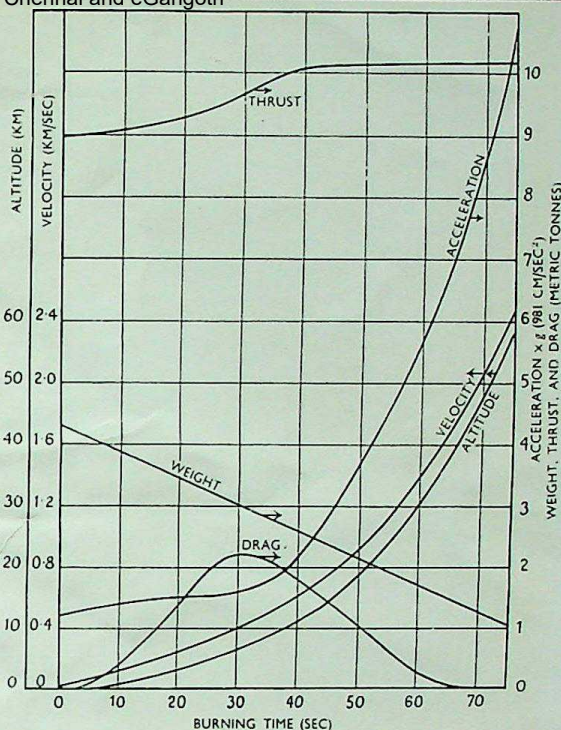


FIGURE 2 - Calculated performance curves for the U.S. Navy's high-altitude sounding rocket Neptune.

and the final velocity at 'all-burnt' is reduced to:

$$V = v \log_e R - gt - F(V, h),$$

where t is the time of combustion, and $F(V, h)$ is a

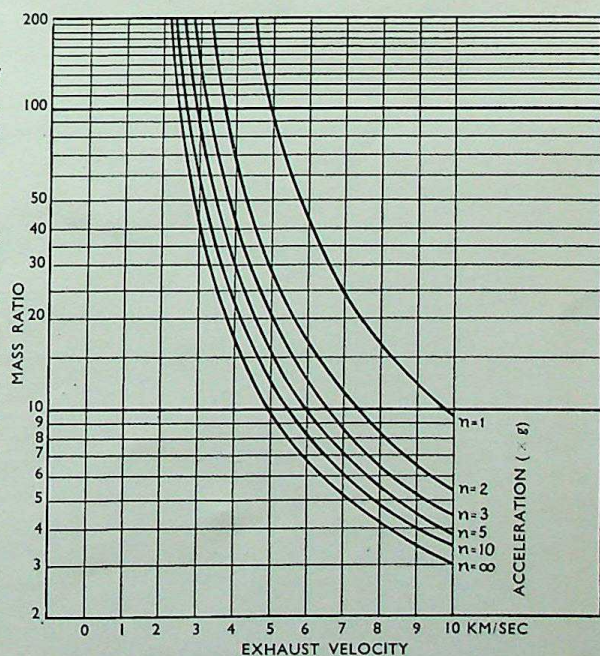


FIGURE 3 - Relationship between exhaust velocity and mass-ratio for rockets of different acceleration.



FIGURE 4 - Photograph of the earth taken from an altitude of 100 miles by means of a V2 rocket launched in New Mexico. An area of more than 200,000 square miles is covered. The curvature of the earth is clearly seen.

term depending in a complex manner on the rocket's shape, altitude, and velocity. Fortunately, as the drag curve in figure 2 shows, air resistance falls practically to zero as the rocket's speed and altitude increase, and the loss in performance due to this cause is not more than 10-20 per cent. It could be reduced substantially by mountain-top launching, which might be worth while in some applications. The gravitational loss gt can also be kept low if high accelerations and hence short periods of burning are used: *Neptune's* final acceleration will be over 10g.

Of the two variables v and R , the former is the more critical because, as it is the logarithm of R that enters into the expression, variations in the value of R have a smaller effect than similar variations in v . Exhaust velocities of 2.5 km/sec have been attained with present-day motors and with fuels of the alcohol-oxygen type. Very much more powerful fuels exist, but it is not yet possible to use them owing to the high temperatures developed. Even present-day fuels have to be used under dilution to restrict chamber temperatures to less than $3,000^{\circ}\text{K}$. When these limitations are overcome, jet velocities of perhaps 5 km/sec may be ultimately attained. There is a tremendous field of research here for the chemist and the metallurgist—how large may perhaps be judged by the fact that during the war over 6,000 rocket fuels were tested at one German establishment alone.

The mass-ratio R is limited by purely engineering considerations, chiefly the dead-weight of motor and fuel tanks. For V2 it was about 3.5; for *Neptune*, as figure 2 shows, it will be just over 4. Possibly twice this ratio may ultimately be attained with a single-stage rocket. Taking a figure of 7, we see that it should eventually be possible to build rockets capable of reaching speeds of $5 \times \log 7$ or 10 km/sec. Allowing for a loss of 2 km/sec against air resistance and gravity, such machines would be able to reach altitudes of 6,000 km.

Such an altitude, though very considerable by any ordinary standards, is only one radius of the earth. To exceed this, and in particular to reach the velocity of escape, is a much more difficult but not an insuperable problem. The possibility of landing an instrument-carrying rocket on the moon is one that has engaged much attention recently. In particular we might mention Chapman's proposal [3] that a magnetometer be sent to the moon to test Blackett's ideas concerning the magnetic field of rotating bodies.

As previously mentioned, the escape from the earth requires a velocity at 'all-burnt' of 11.2 km/sec, and figure 3 shows what this implies in terms of mass-ratio and exhaust-velocity for rockets of different accelerations. The curves show that with fuels and motors in the 3-4 km/sec range, mass-ratios of up to 100 will be needed to reach escape velocity. At first sight it might seem quite impossible to build a rocket weighing say 100 tons, of which 99 tons were fuel while the remaining ton comprised the total weight of structure, motors, fuel tanks, and payload. The difficulty may, however, be circumvented by the device known as the step or multiple rocket.

When a rocket is used to carry a smaller machine to a great height and then dropped off, the upper component will be travelling at a high speed with all its fuel unused. This process may, in theory, be repeated for any number of steps, so that one might have a rocket with an initial mass of hundreds or even thousands of tons, and a final mass of only two or three tons. In this way it would be possible, at least in principle, to design machines capable of reaching the moon or planets, even with chemical fuels. Recent studies indicate that an initial weight of perhaps 50 metric tons would be necessary to land a payload of 50 kg on the moon, but the figures are very sensitive to changes in the assumed exhaust velocity.

It is of interest to note that the step-rocket is no merely theoretical device. In the closing months of the war, about twenty missiles known as *Rheinbote* were fired into Antwerp from a range of about 150 km. Very little information has been released concerning this weapon, but it is known to have been a four-step rocket.

Summarizing these results, we may say that once purely engineering and development problems have been overcome it will be possible to send research missiles into space for immense distances, and, moreover, to receive information from them while they are in flight. One of the most interesting possibilities which this opens up is that of obtaining photographs and television pictures of the moon's hidden face. A less spectacular but perhaps more useful feat would be the steering of rockets into permanent orbits around the earth, from which they could broadcast instrument readings to ground stations for long periods of time. A body travelling horizontally at 8 km/sec just outside the atmosphere would continue to circle the earth for ever, like an artificial satellite, and by a suitable choice of speed a body could be made to move in an orbit at any desired altitude

and with a period of from 1½ hours upwards. The 24-hour orbit, with a radius of 42,000 km, is one which may have important applications, since a body placed in it would always remain fixed over the same spot on the earth. This indicates the remarkable possibility of having scientific instruments permanently fixed in the sky, in apparent defiance of the law of gravitation. It has been suggested that radio repeater stations in such orbits may provide the ultimate solution to the long-distance television relay problem [4].

Although these things would have seemed quite fantastic a few years ago, they are now distinct possibilities of the next decade, for they require no new fundamental knowledge for their achievement. They will open up new fields of science and may well transform much of astronomy and physics. But even that may be merely incidental, for they point the way, clearly and unmistakably, to the ultimate achievement of interplanetary travel—perhaps the most daring dream ever conceived by the minds of men.

To land human beings on the moon, and to ensure their safe return to earth, is obviously a far more difficult task than the mere projection of a guided missile into space. Theoretical studies indicate that it might just be done with step-rockets burning chemical fuels, but the difficulties and the expense would be enormous, since every kilogram taken on the round journey would require at least a ton of fuel at the take-off.

It is now generally agreed that true space-ships capable of reaching other planets will not be practicable until atomic energy is harnessed for rocket propulsion—and of all the applications of atomic energy, this appears to be the most difficult. There is, of course, no doubt that nuclear reactions could produce ample energy for any conceivable interplanetary journey. To quote a striking example, the few kilograms of matter in the Bikini bombs liberated enough energy to take a thousand tons to the moon and back.

The only schemes so far put forward for atomically driven rockets [5, 6] have envisaged the use of very high temperature chain-reactors accelerating gas streams through propulsive nozzles. For a given combustion-chamber temperature, the velocity of the gas from a rocket varies approximately inversely as the square root of its molecular weight. The impulse given to the rocket by the gas jet depends on the momentum of the jet, i.e. its mass $\times$ velocity; thus for a given mass, the gas with lowest molecular weight has the highest exit velocity and so generates the highest momentum. In the chemical rocket the exhaust gases are usually carbon dioxide and steam, but an atomic rocket could use hydrogen or helium as working fluids, since no actual combustion need take place. It could thus produce exhaust velocities three or four times as great at the same chamber temperature as before, with an enormous decrease in fuel requirements. The technical problems involved are exceedingly formidable, but work is proceeding along these lines in America under the NEPA ('Nuclear Energy—Propulsion of Aircraft') project, and perhaps elsewhere. As a glance at figure 3 shows, an increase of exhaust velocity into the 10 km/sec region would reduce the mass-ratios needed for the escape from earth to a value which can be achieved with a single-stage machine of present-day design. Interplanetary return journeys would still require the use of fairly large step-rockets, but the initial weights required would be hundreds instead of scores of thousands of tons.

This is not the place to discuss the possible consequences of interplanetary travel: there have been perhaps too many treatments of the subject elsewhere. It should, however, be patent to all who consider the matter dispassionately that the crossing of interplanetary space will mark one of the great turning-points in human history, for it will end man's physical isolation from the rest of the universe.

REFERENCES

- [1] GODDARD, R. H. 'A Method of reaching Extreme Altitudes' (Smithsonian Misc. Coll., LXXI (1919), No. 2).
- [2] OBERTH, H. *Wege zur Raumschiffahrt* (Munich, 1929; U.S.A., 1945).
- [3] *Nature*, 160, 4064 (20th Sept., 1947).
- [4] CLARKE, A. C. 'Extraterrestrial Relays,' *Wireless World*, Oct. 1945.
- [5] SHEPHERD, L. R. 'The Problem of Interplanetary Propulsion,' *Bulletin of the British Interplanetary Society*, I, 9, Nov. 1946.
- [6] CLEAVER, A. V. 'Interplanetary Flight,' *Journal of the B.I.S.*, VI, 5, June 1947.
- [7] LEY, W. *Rockets and Space Travel* (New York, 1947).
- [8] KOOP, J. M. J., and UYTENBOGAART, J. W. H. *Ballistics of the Future* (Haarlem, 1946).

R. J. GAUTHERET

Methods of growing animal tissues in isolated cultures were perfected more than thirty-five years ago, but plant tissue culture proved more difficult, and complete success was not achieved until shortly before the outbreak of the last war. In this article are described the methods used in plant tissue culture; the use of the cultures in studying problems of morphogenesis, pathology, and physiology; and their application in research upon plant galls.

HISTORICAL

It is now nearly three centuries since the first attempts at structural analysis of organisms led to the discovery of the cell. From subsequent observations on animals and plants, biologists framed the cell theory, according to which the cell represents both a morphological and a physiological unit. Later, the histologists of the classical period established the universality of the cell structure and succeeded in confirming the first point of the theory. They failed, however, to verify the second point, for since they studied only dead organisms cut into thin sections they were unable to demonstrate the physiological individuality of the cell.

In order to establish this point it was, in fact, necessary to show that cells are capable of surviving and multiplying outside the organism. The botanist Haberlandt was the first to realize the importance of an experiment on these lines. As early as 1902 he tried to cultivate various types of plant cells, both epidermal and parenchymatous, but he failed completely, because the elements he used had matured and were too strongly differentiated to multiply *in vitro*.

It was not until 1922 that Robbins in America saw the way which was to lead to success. He assumed that cultivation of plant tissues could succeed only by using cells normally capable of division, i.e. meristematic cells. Some of these cells are located in the tips of plant shoots and roots, where they form small, compact masses called growing points: it was these meristems which Robbins began to cultivate. He isolated root tips and placed them in suitable nutrient media. They grew rapidly and branched, but their proliferation ceased at the end of a few months. In 1934 White resumed these experiments and succeeded for the first time in obtaining unlimited development of isolated roots (figure 1). However, these root cultures were cultures of organs possessing a

definite form and structure, and there could be no hope of obtaining a true tissue culture by this method.

In an attempt to achieve such a true culture the author tried as early as 1934 to cultivate a type of meristem different from that used by Robbins and White. The type of meristem chosen was the cambium, which forms a cylindrical zone inside stems and roots between the phloem and the wood. It is particularly well developed in trees, and its active development ensures growth in diameter. When attempting to cultivate fragments of cambial tissue, it was found that they expanded and produced unorganized parenchymatous masses. The proliferation of such cultures ceased at the end of a few months, but the attempt had nevertheless given promising results; it led to further research, which culminated in the production of true tissue cultures capable of unlimited development. This result was announced by White on 30th December, 1938, by the author on 9th January, 1939, and lastly by Nobécourt on 20th February, 1939.

GENERAL CHARACTERISTICS OF PLANT TISSUE CULTURE

An experiment on plant tissue culture usually begins by placing a fragment of a slightly differentiated organ on the surface of an appropriate nutrient medium, the general composition of which is dealt with below. If a favourable material is used, proliferation starts at once and parenchymatous calluses are seen to form. In this way shreds of tree-bark, pieces of herbaceous shoots or creepers (figure 2), slices of fleshy organs, etc., can be cultivated successfully. 'Explants' proliferate very intensively at first, but proliferation slows down after a few months, then ceases, and finally the cells die.

In order to prolong the activity of the cultures they must be planted out, that is, a fragment of tissue from a rapidly growing region of the original

explant is transferred to a new medium where it can continue its development. This fragment then grows in all directions and is gradually transformed into a more or less rounded mass. At the end of one to two months, according to the species, planting out is repeated, and so on. It is observed that tissue colonies which have been planted out several times have a very different appearance from the corresponding normal tissues, but they have, nevertheless, an entirely characteristic morphology which is the same for a given species. Thus colonies of carrot tissues have a nipped surface with parenchymatous nodules almost isolated from one another (figure 3). Cultures of vine tissues produce very curious digitations on their surface (figure 4), which bear a vague resemblance to the plasmodial veins of certain myxomycetes. On the other hand, the colonies produced by *Scorzonera*, or by Jerusalem artichoke, and others, are almost smooth.

This method, the principle of which is briefly indicated above, has already made it possible to cultivate tissues of numerous plants, all dicotyledonous, and we have actually isolated nearly thirty different strains (hawthorn, willow, vine, Virginia creeper, tobacco, snapdragon, carrot, Jerusalem artichoke, and some other species, are almost more than ten years old).

These strains derive from the proliferation of normal plant tissues, but it has also been possible to cultivate pathological tissues, especially gall tissues. White, to whom we owe the first work on this kind of tissue, isolated a strain from genetic galls spontaneously produced by certain tobacco hybrids. Collaborating with Braun, he succeeded later in cultivating tissues of crown gall from sunflower and *Vinca*. It should further be noted that Morel also produced crown gall tissues, proceeding from galls in tobacco, *Abutilon*, and other plants. In the United States, Black succeeded in developing tissues of very peculiar galls produced by certain viruses. Finally, we provoked a remarkable gall process by subjecting normal tissue cultures to prolonged treatment with heteroauxins. After treatment the cultures behaved like typical gall cultures and, in particular, presented the principal morphological and physiological properties of crown gall tissue cultures.

For the purpose of establishing as close a comparison as possible between normal tissues and gall tissues, research workers have endeavoured to obtain cultures of both kinds of tissue from the same plant, in some cases with success; for instance, from Jerusalem artichoke we isolated a strain of

normal tissue and a strain of crown gall. Morel also obtained these two types of culture for vine and tobacco. For *Scorzonera* we even produced three kinds of cultures: cultures of normal tissues, of crown gall tissues, and of 'chemical galls' produced by the prolonged action of heteroauxin. The comparative study of these three types of cultures should enable us shortly to solve various problems in connection with gall phenomena in plants.

To conclude this examination of the general characteristics of tissue cultures, we may point out that research workers have not confined their attention to the external morphology of tissue colonies but have also examined their anatomical structure. These studies revealed the existence of two types of organization. In a few cases, e.g. willow or certain vine strains, the colonies are entirely parenchymatous (figure 5) and therefore represent pure cultures of a single type of cell; but more often the structure is heterogeneous, and in such cases they are composed of a fundamental parenchymatous mass (figures 6 and 7), permeated by more or less well-defined vascular strands in which can be seen xylem elements and sieve tubes associated with cambium cells. Such colonies must be regarded as cultures of cambium and its derived tissues.

NUTRIENT REQUIREMENTS OF PLANT TISSUE CULTURES

Culture media permitting the proliferation of plant tissues always contain water, agar as a solidifying agent, mineral salts, an organic source of carbon (glucose or sucrose), and very often traces of some organic substances acting as growth factors (vitamin B₁, glycocoll, indoleacetic acid, cystine, biotin, pantothenic acid, etc.). Repeated trials have established that all tissues have approximately the same requirements of mineral salts and sugars, but their requirements of growth factors differ according to the species. Certain tissues, such as Jerusalem artichoke, Virginia creeper, and others, cannot develop if the medium contains no heteroauxin (figure 8) but show very active proliferation if it contains traces of indoleacetic acid or some other heteroauxin (figure 9). Other tissues, especially willow and hawthorn, are more specific in their requirements; here a culture can be obtained only if the medium contains the three following growth factors: indoleacetic acid, biotin, and pantothenic acid. Others again, e.g. carrot and chicory, can be cultivated on a medium containing only mineral salts and



FIGURE 1 - Isolated root cultures (White). These photographs show isolated roots derived from strains which had been transferred several times.

Top left, *Petunia*.

Top right, *Trifolium repens*.

Bottom left, *Nicotiana Langsdorffii*.

Bottom right, *Daucus carota*.



FIGURE 3 - Carrot tissue culture, two months old, derived from a ten-year-old strain transferred 58 times. The colony is seen to present a mammillate surface with plasmodial nodules almost isolated from each other. ($\times 6.5$)

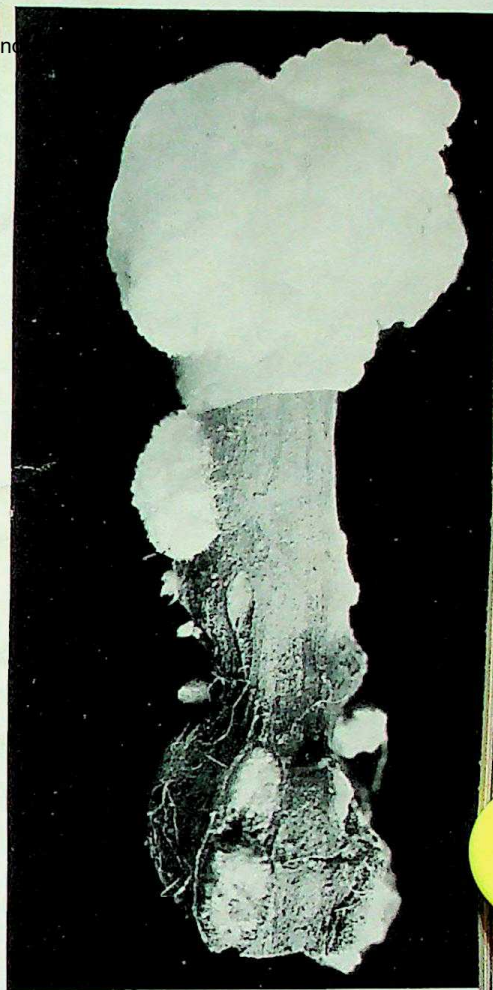


FIGURE 2 - Fragment of vine shoot after two months. Note that it has developed to form a large protuberance. ($\times 5$)



FIGURE 4 - Vine tissue culture two months old, derived from a ten-year-old strain. The surface of the culture has produced digitations resembling the plasmodia of certain myxomycetes. ($\times 18$)

(Vincent, photo)

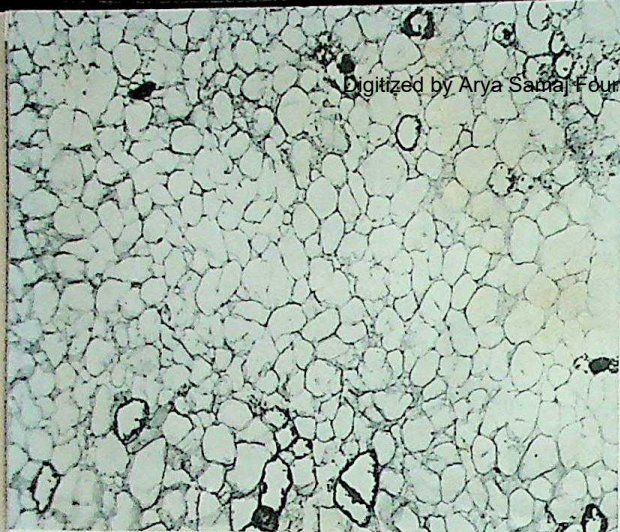


FIGURE 5 - Section of a vine parenchyma culture. The tissue is seen consist solely of parenchymatous elements. The black cells are cells containing tannin which has been precipitated by the fixative. ($\times 60$)



FIGURE 6 - Section of a Jerusalem artichoke tissue culture, derived from a seven-year-old strain transferred 41 times. Note that the culture is composed of a parenchyma containing cribovascular nodules.

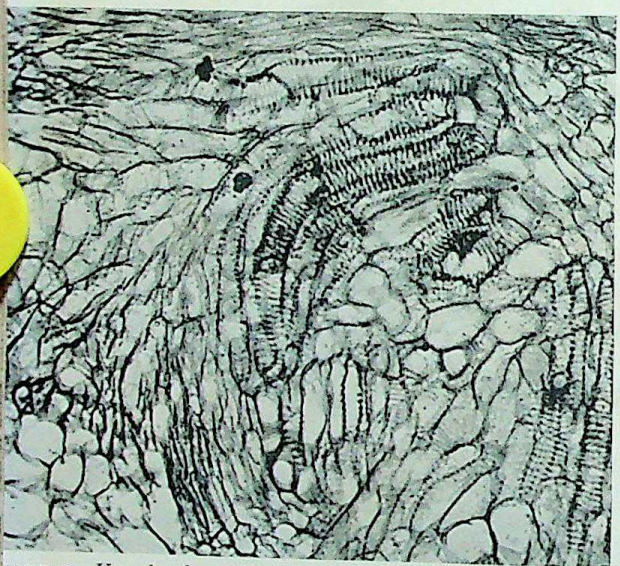


FIGURE 7 - Vascular formations developed in a chicory tissue culture. Differentiated elements can be distinguished surrounded by sieve tube areas. Between these two tissues can also be seen rudimentary cambium. ($\times 300$)

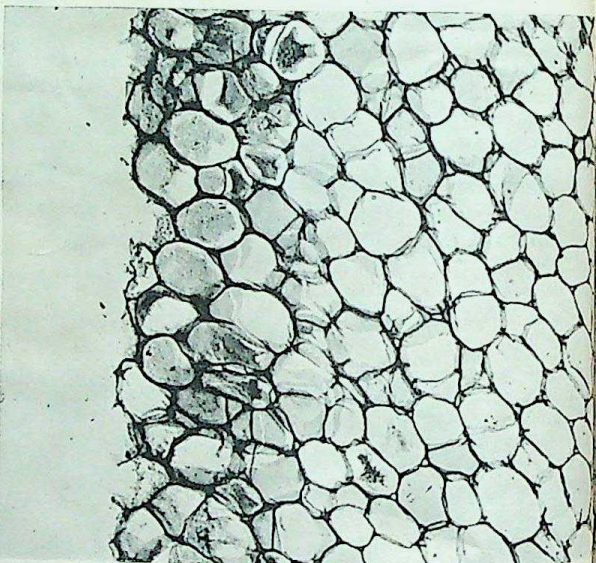


FIGURE 8 - Section of a fragment of Jerusalem artichoke tissue cultivated for two months in a medium containing no heterocytokinin. The cells have not multiplied. ($\times 90$)

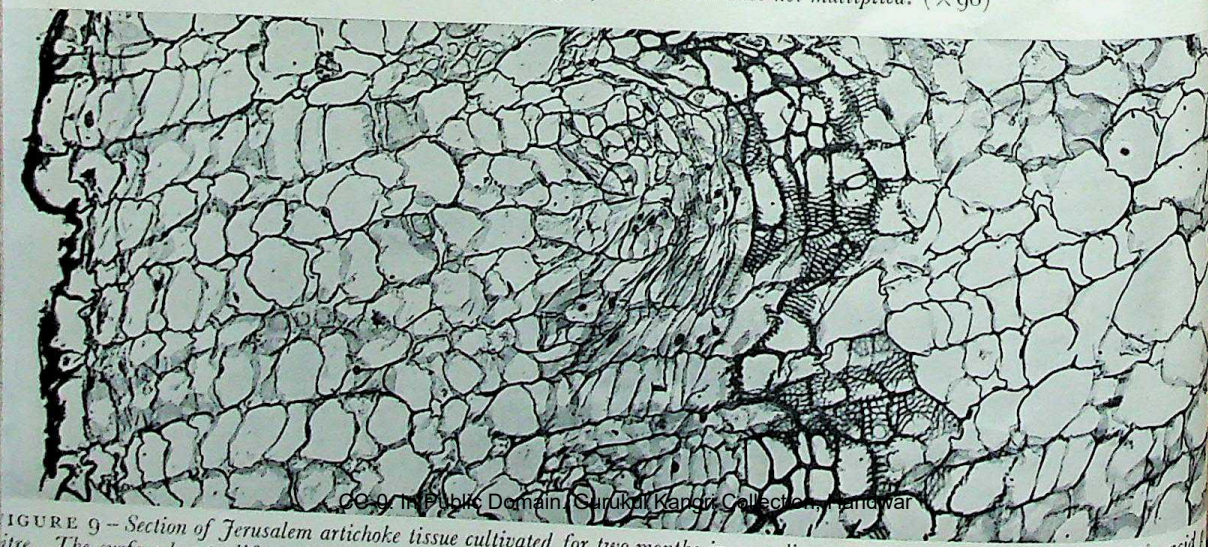


FIGURE 9 - Section of Jerusalem artichoke tissue cultivated for two months in a medium containing 0.0001 gm indoleacetic acid per litre. The surface has proliferated to form a sort of parenchyma within which are vascular elements composed of a phloem island.

glucose,¹ but the presence of growth factors is likely to intensify proliferation. Finally, it should be noted that gall tissues, whatever their origin (genetic, bacterial, virus, or chemical), can be cultivated in the absence of heteroauxin and are almost insensitive to the formative stimulant action of substances of this type.

Recent experiments by Skoog and de Ropp support the assumption that this very peculiar behaviour of gall tissues is due to the fact that they produce a substantial quantity of indoleacetic acid.

PLANT TISSUE CULTURE AND MORPHOGENESIS

The study of tissue cultures makes it possible to analyse the conditions of development of the plant organs, e.g. the determination of rhizogenetic processes has been defined by means of the reaction of heteroauxins on tissues cultivated *in vitro*, and the factors influencing the initiation of bud-formation have been investigated by the use of tissue cultures. During research on tobacco tissue cultures, White found that the production of leaf primordia is facilitated by immersing the colonies in the nutrient medium. This result was confirmed by Skoog, who also examined the effects of light, temperature, and heteroauxins on bud-formation, and investigated the conditions under which organs may produce undifferentiated colonies or vice versa. Bud-determination has also been studied by the author, who used elm cambial tissue.

With regard to more particular problems of morphogenesis, tissue culture has enabled us to analyse the histogenetic processes. Thus anatomical observations of tissue cultures of carrot, Jerusalem artichoke, chicory, etc., have shown that the meristem zones always appear at the boundary separating two tissues of different kinds. These studies also made it possible to analyse the method of development of cribrovascular strands appearing inside originally homogeneous tissues. Some remarkable experiments carried out by Camus have shown that buds grafted *in vitro* have a histogenetic action involving de-differentiation processes followed by differentiation and organization phenomena.

Lastly, Buvat discovered the morphological

¹ In order to prevent the interference of impurities likely to contain growth factors, it is necessary in certain experiments to abandon the use of agar for solidifying the nutrient media and cotton wool for plugging the culture vessels. Glass fibre soaked in a nutrient solution is used as solid support, and tinfoil caps are employed to close the vessels.

mechanism of the de-differentiation of tissues cultivated *in vitro*, by cytological analysis of these processes. Thanks to the technique of tissue culture, precise new knowledge has been gained of the phenomena of polarity. In particular, numerous experiments on fragments of carrot and chicory roots have shown that polar plant development is the result of a hormonal mechanism, characterized by the conveyance of a morphogenetic substance from the leaf towards the root.

PLANT TISSUE CULTURES AND PHYSIOLOGY

The original aim of the workers who developed the first cultures *in vitro* was to determine the chemical factors in cellular multiplication. The results obtained with isolated roots by Robbins, White, and Bonner have long since established the fact that proliferation of root meristems requires mineral salts, a simple sugar (glucose or sucrose), and some other organic substances—e.g. glycoll, vitamin B₁, vitamin B₆, and nicotinic acid—the nature of which varies according to the species.

Further research on tissue cultures, however, led to quite different results. Tissues cultivated *in vitro* can in fact proliferate in the absence of the substances just named, but in certain cases other factors must be provided. These have been mentioned previously—heteroauxin, biotin, pantothenic acid.

The use of tissue culture thus represents an excellent method of studying cell nutrition. It should make it possible to assess the value of all substances (cystine, traumatic acid, etc.) which have been considered, without proof, as stimulants of proliferation. In our opinion the highly obscure problem of neoformative substances, such as caulocaline and rhizocaline, may be solved by this method.

PLANT TISSUE CULTURES AND PATHOLOGY

We shall conclude this account with a very brief indication of the results obtained in plant pathology by means of tissue culture.

The first work in this field was done by White. In 1934 he tried to use isolated tomato roots to cultivate virus proteins, which, as we know, are incapable of growth in inert media. Segrétain reached similar results by using tissue cultures. Recently Morel extended this method to the culture of certain obligate parasites such as downy mildew and oidium of the vine. Tissue culture has also furnished important results in the study of galls, especially crown gall.

HISTORY OF THE PHYSICAL SCIENCES

The Growth of Physical Science, by the late Sir James Jeans. Pp. x + 364, with a frontispiece and 13 plates. University Press, Cambridge. 1947. 12s. 6d. net.

Sir James Jeans was not only a scientist of the first rank but possessed the rare and enviable gift of interpreting science to the layman. His popular books on cosmology had, and still have, a very wide circulation, and his public lectures always drew large audiences. The present book, which describes the main lines of advance of physical science (including astronomy and mathematics), will doubtless prove equally successful among uncritical readers, for it possesses all the lucidity and charm of style of its predecessors. The historian of science, however, will not be able to pass a wholly favourable judgment upon it. The broad outlines are drawn with all Jeans' accustomed skill, and in the fields with which he was particularly familiar the details are accurate and well selected. There are, however, far too many minor errors in the book as a whole. For example, it is implied that alchemy ceased to be practised in Alexandria after Diocletian's decree against it; a celebrated Muslim mathematician is described as al-Kirismi instead of al-Khwarizmi; the Arabs are correctly stated to have taken their numerals from India, but no mention is made of their fundamentally important addition of the cipher; Mayow's work on combustion is overrated; and there are numerous misprints such as Mikola for Nikola (Copernicus), Humphrey for Humphry (Davy), Hayyam for Hayyan (Jabir), Canizzaro for Cannizzaro, and Amerigo for Amedeo (Avogadro). These and similar errors, though each is small in itself, are in fact so numerous as to form a serious blemish on what might have been an excellent book. They should be corrected in future editions or impressions.

PARTICLE TRACKS

Nuclear Physics in Photographs; tracks of charged particles in photographic emulsions, by C. F. Powell and G. P. S. Occhialini. Pp. viii + 154, with 50 plates. Oxford University Press. 1947. 18s. net.

Nuclear physics has become so much a matter of elaborate and expensive engineering—cyclotrons, betatrons, and

the like—that it is refreshing to see that there is one important line of work which uses nothing more abstruse than a photographic plate and a microscope. It is true that the plates now used are of a rather special type, but the earliest work was done with quite ordinary ones. It has been known for a long time that a photographic plate records the passage of certain ionizing particles, such as the alpha rays ejected from radium, and that under suitable conditions and magnification the track of a single particle can be seen as a closely spaced row of dots in the photographic emulsion. Attention was directed to the method shortly before the war, when two Viennese ladies, Drs Blau and Wambacher, discovered that plates left for some time near the top of a mountain showed after development remarkable 'stars,' consisting of from two to twenty tracks diverging from a point and apparently representing the paths of fragments of an atom smashed by a cosmic ray. Dr Powell and his co-workers at Bristol have made a prolonged study of these effects, and have also applied the method to study the tracks produced in the emulsion under the action of other kinds of radiation.

The present work is, as regards its text, a short and clearly written account of the elementary principles of nuclear physics, each chapter of which is illustrated by a number of plates showing tracks of particles which exemplify the principles in question. These plates are truly magnificent and show the great progress that has been made in the technique, largely owing to the excellent work done by the research staff of Ilford's in preparing improved photographic emulsions. These pictures make the processes of nuclear physics extraordinarily vivid. In a great many ways the method is similar to that of the Wilson Chamber, but it has an advantage in recording rare events because the plate can store up all that happens to it over a period of weeks.

Very recently the work of Powell has made it nearly certain that there is more than one kind of 'heavy electron' or meson, the first of which was discovered in cosmic rays, shortly before the war, by Anderson. It has also become very likely that there is also an uncharged meson, a sort of poor relation of the neutron. The number

of 'elementary' particles is thus rising fast, and the old simplicity of proton and electron has gone. But this increasing complexity is a healthy sign: it is the indication that a new synthesis is not far away. G. P. THOMSON

PALAEOBOTANY

An Introduction to Palaeobotany, by Chester A. Arnold. Pp. 431, with 187 figures. McGraw-Hill Publications, London. 1947. 27s. 6d. net.

Books on fossil botany have never been abundant. During the past decade they have, in fact, been rather scarce, as some of the major texts have been out of print. It is to make good this deficiency that Professor Arnold of the University of Michigan has prepared this volume. His aim was to produce an up-to-date, concise, yet sufficiently comprehensive book for the use of students, and thereby to sustain and promote an interest in palaeobotany and to convey some idea of the importance and value of this subject to both botanists and geologists. It may be said at once that the author has succeeded admirably in this task: he has written a book which will be welcome wherever a lively interest in the evolution of plants is maintained.

The book contains much information of the kind that an advanced student will particularly want to know: the techniques by which fossils may be studied, and how the data which they yield shed light on the evolution of the major classes of plants. In some instances support is lent to the classical views; in others, new views are propounded, or a suspension of judgment is advocated until our knowledge is further extended. The author is enthusiastic about his subject but cautious in the interpretation of his material.

Certain chapters centre around major groups of plants, while other chapters deal with special topics such as the geological sequence of plants. Professor Arnold, though not pessimistic, treads warily where phylogenetic reconstructions are concerned. 'As yet,' he says, 'we have not been able to trace the phylogenetic history of a single group of modern plants from its beginning to the present.' This is very true, though perhaps not always realized.

C. W. WARDLAW

A quarterly review designed to record the progress
of the sciences in the service of mankind

VOLUME VII

JULY 1948

NUMBER 27

Symbolism in science

In the present issue we publish an article by Mr D. I. Duveen on symbols used by the alchemists. This may direct our attention to the wider topic of the place of symbols and symbolism in science as a whole—a topic of considerable practical importance no less than of historical and philosophical interest. It is pertinent to recall that the original meaning of the word symbol was a creed or a confession of faith, for in effect that is the significance of many scientific symbols of today. When, for example, we say that the gravitational force f between two masses m_1 and m_2 at a distance a is equal to $k \times (m_1 \cdot m_2)/a^2$, we are expressing the belief of the scientist that any two masses will in fact be found to behave in this way. In the same way the basic curve of the horse-chestnut leaf may be represented as $r = \sin(\theta/2) \cdot \sin n\theta$, though perhaps the affirmation of belief in this case is not accompanied by such a profound conviction of its universality.

The use of symbols in science is well known to be of great antiquity, and to have early acquired a sophisticated character. Thus in a Babylonian tablet of the seventeenth century B.C., dealing with the preparation of a lead glaze coloured with copper, the Sumerian ideogram for 'eagle' is used. This sign has the Semitic value of *erû*, meaning copper, which is obviously the sense in which the initiated reader is expected to interpret it. Commoner than this punning source of symbols was their derivation from the natural occurrence of substances; so sulphur, for instance, which is sometimes to be found floating on Mesopotamian streams, was known to the Assyrians as *kibir nâri* ('bank of the river'), whence the Arabic name *kibrî* still current (though it now usually means 'matches'!). Symbols also derived from resemblances in shape, colour, and other properties, as with the circle of the sun to symbolize gold and the crescent of the moon to

represent silver. A further origin of symbols lay in the employment of contractions, many of which ultimately became mere conventional signs. Finally there are those numerous early scientific or pseudo-scientific symbols which owed their origin to religious, philosophical, or magical beliefs and practices, or to folk-lore.

In early times, possession of scientific and technical information was confined to comparatively few, and was correspondingly valuable. One of the principal purposes of symbolism was therefore, as Mr Duveen points out, to conceal professional knowledge from the layman. Before technical writings could be interpreted it was necessary for the student to learn a whole language of symbolism, in the process of which he was doubtless assessed by his teachers as to his fitness for the particular craft or profession.

Symbolism, however, had another aspect. Largely owing to Gnostic influence, mystical force was attached to words, letters, and signs, which thus became more than mere representations and were attributed with actively operational functions. This belief led to the widespread custom of wearing amulets, talismans, and engraved gems—such as the abraxas of Basilides (second century A.D.), in which was embodied the number of days in the year as signifying the 365 orders of spirits emanating in succession from the Supreme Being. Gnostic talismans of this and similar kinds were used in all parts of the ancient world—even in Britain, for in 1827 a specimen was unearthed near the Roman fort of Segontium in North Wales.

Symbolism found a further field of application in the doctrine of signatures, which taught that the external characters of plants indicated the diseases for which Nature had intended them as remedies. 'Sin and Satan,' wrote a seventeenth-century naturalist, 'have plunged mankind into an

ocean of infirmities, yet the mercy of God, which is over all His workes, maketh grasse to growe upon the mountains and herbes for the use of men, and hath not only stamped upon them a distinct forme, but also given them particular signatures, whereby a man may read even in legible characters the use of them.' Even John Ray, who expressed some scepticism over the doctrine, believed that 'noxious and malignant plants do, many of them, discover something of their nature by the sad and melancholick visage of their leaves, flowers, or fruit.' The conception lying behind the theory of signatures was the perennially stubborn belief in a real connection between object and image, a belief universally held until the growth of modern science and still not without its superstitious adherents.

We no longer believe that the sigillary marks in the rhizomes of Solomon's Seal (*Polygonatum multiflorum*) indicate that the plant is suitable for curing 'any bruise, black or blue spots, gotten by falls, or women's wilfulness in stumbling upon their hasty husbands' fists—we relegate such fables to the obscurity they merit. Yet perhaps as we do so an uneasy suspicion is aroused: are we not ourselves inclined to attach too much importance to signs and symbols in science, and to think that when we have found a formula we have explained a phenomenon?

It is a suspicion worth attention, even though the principal object of scientific symbolism is obviously to convey information rather than to obscure it, and to be precise rather than vague. Take the chemical formula CH_3COOH . This to a chemist is an epitome of the chemical behaviour of acetic acid: among other things it tells him that the molecule of acetic acid is sixty times as massive as one-sixteenth of the atom of oxygen, that the acid is an oxidation product of acetaldehyde, that it has one hydrogen atom replaceable by a metal, that it has three hydrogen atoms replaceable by chlorine, that it possesses a sour taste and a comparatively low boiling-point, and that it is miscible with water. The same sort of concentrated factual knowledge is of course to be found in all other chemical formulae, which nowadays constitute an essential factor in the advance of both pure and applied chemistry. It should nevertheless be

remembered that a chemical formula, like other formulae used in science, conveys only selected information, and that too complacent a reliance upon symbolism may lead to a mental sclerosis. When the schoolboy heats sulphur with iron filings and neatly rounds off his account of the experiment by writing $\text{Fe} + \text{S} = \text{FeS}$ he feels that he knows all there is to be known about that particular chemical change. *Mutatis mutandis*, older scientists not seldom succumb to the same deceptive euphoria, the aesthetic satisfaction of tidy symbols distracting their attention from problems still unsolved.

The tendency to unwarranted complacency shown by unreflective scientists is most marked when a phenomenon can be described by an elegant mathematical expression, for, in spite of abounding evidence to the contrary, we are all prone to think that the simplest of equally possible explanations must necessarily be the correct one. But, in science at least, mathematical expressions are of the same fundamental character as other signs and symbols; that is, they are concise descriptions and possess no greater authority. As observation grows and experiment extends, the possibility follows of ever closer accuracy in description: Newton's mechanics is subsumed in Einstein's, and the history of science gives us no reason to suppose that Einstein has said the last word. Mathematics affords science a distilled symbolism, but a symbolism nevertheless; the facts it symbolizes and correlates are the product of the laboratory. Yet since mathematics affords the most precise form of description it is for mathematical expression that science should strive. In the words of Sir D'Arcy Wentworth Thompson: 'Not only the movements of the heavenly host must be determined by observation and elucidated by mathematics, but whatsoever else can be expressed by number and defined by natural law. This is the teaching of Plato and Pythagoras, and the message of Greek wisdom to mankind. So the living and the dead, things animate and inanimate, we dwellers in the world and this world wherein we dwell— $\text{πάντα γὰρ μὲν τὰ γινωσκόμενα}$ —are bound alike by physical and mathematical law.'

Editor: E. J. HOLMYARD, M.A., M.Sc., D.Litt., F.R.I.C.

Deputy Editor: TREVOR I. WILLIAMS, B.A., B.Sc., D.Phil.

Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1

Chemical properties and structure of the penicillins

E. CHAIN

In spite of difficulties arising from its instability and from the extremely small quantity of material originally available, penicillin (a British discovery) has been more intensively studied by chemists than perhaps any other organic compound whatsoever. Its investigation has opened up completely new fields in the chemistry of heterocyclic compounds. This authoritative article is based upon the chemical reports, nearly seven hundred in all, prepared during the Anglo-American research on penicillin during and since the recent war.

HISTORICAL

In the first paper on penicillin Fleming [1] drew attention to the fact that it was an unstable substance. The instability of penicillin was also emphasized by Clutterbuck, Lovell, and Raistrick [2], who carried out the first chemical investigations on this substance.

The instability of penicillin was undoubtedly the chief reason for the fact that eleven years elapsed between its discovery by Fleming in 1929 and the discovery of its unique chemotherapeutic properties by the Oxford workers [3]. Its instability was one of the main reasons for the decision made by Chain and Florey in 1939 to reinvestigate its properties, for it was anticipated that the study of a substance with such unusual chemical properties would probably lead to interesting biochemical discoveries.

Clutterbuck, Lovell, and Raistrick had shown that penicillin was an acid of low molecular weight which to a large extent could be extracted from the acidified culture medium into ether, but the antibacterial activity of the ether extract was lost on evaporation of the solvent. The Oxford workers [4] showed that the antibacterial activity could be transferred without loss from the ethereal solution into aqueous solution by adding the correct amount of alkali to bring the solution to neutrality. The aqueous solution containing a salt of penicillin could be evaporated to dryness from the frozen state in a vacuum without loss of activity. The dry preparations thus obtained were brown hygroscopic powders which preserved their antibacterial power for long periods if kept dry. These preparations were shown to possess remarkable powers of protecting mice against infections with *Streptococci*, *Staphylococci*, and *Vibrio septique* which would otherwise prove fatal. Later it was demonstrated with purer preparations that peni-

cillin was also extremely effective in combating many of the most important and dangerous infections in man [4].¹

After the recognition of the remarkable clinical value of penicillin as a chemotherapeutic agent against infectious diseases the elucidation of its chemical structure became a matter of great urgency and importance.

Towards the end of 1942 Dr Wilson Baker (now Professor of Organic Chemistry in the University of Bristol) and Sir Robert Robinson joined Drs Chain and Abraham in the chemical studies on penicillin. This team of workers was responsible for all penicillin degradation studies at Oxford. Dr J. J. Cornforth, and later many other members of the Dyson Perrins laboratory, Oxford, joined in the synthetic studies. Dr E. R. Holiday, of the London Hospital, working in the Department of Biochemistry at Oxford, collaborated on the ultra-violet absorption measurements, and Drs H. W. Thompson and R. E. Richards on investigation of infra-red spectra.

The main handicap to the penicillin degradation studies at Oxford was shortage of material. Most of the work was carried out with preparations made in the small production plant at the Sir William Dunn School of Pathology. The total amount of penicillin available to the Oxford workers was, in terms of pure material, about 1.5–2 gm, but of this only a few hundred milligrams were in the form of highly purified material, whereas the bulk of the work was carried out with material of only 50–60 per cent. purity. Under these circumstances the collaboration of Mrs Dorothy Hodgkin and Mrs B. Rogers-Low of the Department of Crystallography, Oxford, and of Dr C. W. Bunn and others at the laboratory of Imperial Chemical Industries at Winnington, was

¹ For a review of the early work on penicillin see also [6].

of particular value. By means of X-ray crystallographic studies on degradation products of penicillin, physicochemical data were obtained which made possible their identification even when available only in very small amounts. X-ray crystallographic studies on single crystals of the sodium, rubidium, and potassium salts of penicillin have played an important part in the final elucidation of the structure of the penicillin molecule, making possible a conclusive decision between alternative formulae.

Other groups of chemists in England, both academic and industrial, began to take interest in the chemical investigations on penicillin. A group at the Imperial College of Science, London, under the leadership of Dr A. H. Cook and Professor Sir Ian Heilbron, and groups at the firms of Glaxo Laboratories, Burroughs Wellcome Ltd., and Imperial Chemical (Pharmaceuticals) Ltd. started investigations. Later the following groups also participated: Department of Chemistry, Manchester University; Departments of Chemistry and Colloid Science, Cambridge University; National Institute for Medical Research, London; British Drug Houses Ltd.; Boots Pure Drug Company Ltd.; May and Baker Ltd.; and Imperial Chemical Industries Ltd., Alkali Division.

Simultaneously, American chemists began work on the structure of penicillin. The American work was carried out on a very large scale. The following academic, governmental, and industrial laboratories participated in it: Cornell University Medical College, Department of Biochemistry and Russell Sage Institute; Federal Security Agency, Food and Drug Administration; Harvard University, Department of Chemistry; University of Illinois, Department of Chemistry; University of Michigan, Departments of Chemistry and Physics; National Bureau of Standards; Northern Regional Research Laboratory, U.S. Department of Agriculture; Rockefeller Institute for Medical Research at Princeton; Abbott Laboratories; Cutter Laboratories; Heyden Chemical Corporation; Eli Lilly and Co.; Merck and Co. Inc.; Parke, Davis and Co.; Chas. Pfizer and Co. Inc.; Shell Development Company; Squibb Institute for Medical Research; the Upjohn Company; and Winthrop Chemical Company Inc.

In 1943 the governments of Great Britain and the United States imposed a security ban on all information relating to the chemical investigations on penicillin. This ban remained in force until the end of 1945. Soon after its introduction the British chemists engaged in research on peni-

different groups with a view to exchanging information. Dated reports, known as the 'PEN' series, were sent to the secretary of this committee, and were regarded as equivalent to publications which normally would have been sent to the scientific journals. Most of the British degradation work on penicillin was carried out between May and October, 1943, and is contained in the 'PEN' reports.

The American work on penicillin was at first done independently of the British work. After the imposition of the publication ban on penicillin chemistry the Medical Research Council in Great Britain and the Office of Scientific Research and Development in the United States started negotiations with a view to establishing a regular exchange of information between the American and British groups of chemists. Agreement was reached early in 1944. The Medical Research Council set up the Committee for Penicillin Synthesis, which replaced the unofficial committee mentioned above and to which the British workers now sent their progress reports. These became known as 'CPS' reports. Similarly the American workers sent in monthly reports to the Office of Scientific Research and Development. The British and American reports were circulated among the accredited workers on penicillin chemistry.

The magnitude of the combined Anglo-American effort on penicillin chemistry can be gauged from the fact that nearly 700 reports were received by the American and British Government organizations co-ordinating the chemical work on penicillin.

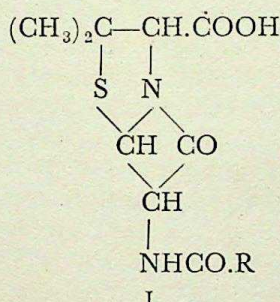
This international collaboration continued until the end of 1945 and proved very fruitful. Though its chief aim, a workable synthesis of the penicillin molecule capable of replacing the fermentation method of production, was not achieved, a great deal of valuable information of great scientific interest was collected. The work embodied in the reports deals with degradation studies, the synthesis of degradation products, model compounds and intermediates for projected penicillin syntheses, and different physico-chemical investigations such as infra-red spectra and X-ray crystallographic investigations. The reports are now open for inspection in various libraries in Great Britain and the United States. A compendium of these reports, in the form of a comprehensive Anglo-American monograph on penicillin chemistry, is in the process of being published by the Princeton University Press under

the auspices of the National Academy of Sciences, Washington, D.C.

In the following pages it is proposed to give a brief account of the main results of the Anglo-American work on the structure of the penicillin molecule. It is not intended to follow strictly the historical course of events, and the number of references will be limited to a minimum. A more detailed account is in course of publication [7].

MULTIPLICITY OF THE PENICILLINS. CHEMICAL AND PHYSICAL PROPERTIES

It became clear at an early stage of the structural investigations that penicillin was not a single substance, but that there existed a number of penicillins having very similar chemical and biological properties but differing in their chemical composition. It was shown that the penicillins possessed a common nucleus but differed in the nature of a side chain. The structural formula for the penicillin molecule at present generally accepted is represented below (I):



The penicillins were at first differentiated by Roman numerals or letters, but eventually a nomenclature was adopted according to which they are differentiated by prefixes indicating the nature of the side chain, e.g. benzylpenicillin, in which $\text{R} = \text{C}_6\text{H}_5\text{CH}_2$; heptylpenicillin, in which $\text{R} = \text{C}_7\text{H}_{15}$; and so on. In table I are given the names and empirical formulae for some penicillins isolated from mould culture filtrates.

The penicillins are strong monobasic acids, with a pK of about 2.9. There is no indication of

the presence of a basic group in the electrotitration curve, and even if the titration is carried out in glacial acetic acid with perchloric acid as titrating acid no sign of a basic group can be detected. This absence of a basic group, even of a very weak type, in the penicillin molecule has been of great significance in structural considerations.

Determination of the molecular weights of the penicillins by different methods showed that they possessed molecular weights corresponding to the simple formulae represented in table I.

Benzyl- and *p*-hydroxybenzylpenicillin show the ultra-violet absorption characteristic of the benzene nucleus, but the penicillins with aliphatic side chains show no characteristic ultra-violet absorption.

In the form of the free acids the penicillins are soluble in ether, chloroform, and esters, and can be extracted from acidified aqueous solutions into these solvents (with the exception of *p*-hydroxybenzylpenicillin, which cannot be extracted with chloroform). In the above-mentioned organic solvents the penicillins are stable for many days at temperatures below 7°C . In aqueous solutions the penicillins are stable only at a pH ranging between 5 and 8, i.e. in the form of their salts. In acid or alkaline solutions they rapidly lose their biological activity. The alkali salts of the penicillins crystallize readily. MacPhillamy and Wintersteiner were the first to obtain a penicillin salt in the crystalline state; in July 1943 they crystallized the sodium salt of benzylpenicillin. Apart from the alkali salts no other metal salts of the penicillins have been obtained in the crystalline state, but several crystalline salts with organic cations have been prepared by direct combination of the bases with the free penicillin acids in organic solvents (for example the triethylamine, *N*-ethylpiperidine, and procaine salts). Under these conditions the salts precipitate from solution. The inactivation of the penicillins in acid or alkaline solutions is accompanied by a change of solubility and acid-base properties. The products of inactivation are *zwitter-ions* possessing two acid groups and one basic group and are insoluble in

TABLE I

Name of Penicillin	Formula of Side Chain	Empirical Formula
Δ^2 -Penicillin	$\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}=\text{CH}\cdot\text{CH}_2-$	$\text{C}_{14}\text{H}_{20}\text{O}_4\text{N}_2\text{S}$
Δ^3 -Penicillin	$\text{CH}_3\cdot\text{CH}=\text{CH}\cdot\text{CH}_2\cdot\text{CH}_2-$	$\text{C}_{14}\text{H}_{20}\text{O}_4\text{N}_2\text{S}$
<i>n</i> -Amylpenicillin	$\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{CH}_2-$	$\text{C}_{14}\text{H}_{22}\text{O}_4\text{N}_2\text{S}$
<i>n</i> -Heptylpenicillin	$\text{CH}_3\cdot(\text{CH}_2)_5\cdot\text{CH}_2-$	$\text{C}_{16}\text{H}_{26}\text{O}_4\text{N}_2\text{S}$
Benzylpenicillin	$\text{C}_6\text{H}_5\cdot\text{CH}_2-$	$\text{C}_{16}\text{H}_{18}\text{O}_4\text{N}_2\text{S}$
<i>p</i> -Hydroxybenzylpenicillin	$\text{HO}\cdot\text{C}_6\text{H}_4\cdot\text{CH}_2-$	$\text{C}_{16}\text{H}_{18}\text{O}_6\text{N}_2\text{S}$

organic solvents. Both have been isolated in the crystalline state. Electrometric titrations showed that the products of acid inactivation differ from those of alkaline inactivation. The former were termed penillic acids; they are isomeric with the penicillins and possess a basic group with a pK of 7.6. The latter were termed penicilloic acids; they are hydrolysis products of the penicillins, containing an additional molecule of water, and possess a basic group with a pK of 5. Both degradation products have played an important part in the elucidation of the structure of the penicillin molecule as a whole. Their structures will be discussed below.

The penicillins lose their biological activity under the influence of many reagents other than acid and alkali. Thus they are inactivated by several metal ions, including zinc, cadmium, lead, mercury, and copper; the action of these metal ions is catalytic. The penicillins are also inactivated by primary alcohols and amines, ketonic reagents such as hydrazine and hydroxylamine, the amino-acid cysteine, and an enzyme, produced by several bacterial species, termed penicillinase.

The penicillins are stable towards reducing agents. The penicillins readily react with catalytically activated hydrogen to give amylpenicillin.

All penicillins are stable towards iodine in neutral solution but are rapidly destroyed by bromine. They are destroyed also by oxidizing reagents such as hydrogen peroxide and potassium permanganate.

The carboxyl group in the penicillin molecule can be esterified by diazoalkanes, and the methyl and ethyl esters have been obtained crystalline. The methyl ester of benzylpenicillin possesses only weak antibacterial activity *in vitro* but is as active as the alkali salts *in vivo*, presumably because it is hydrolysed by a hydrolytic enzyme in the tissues. An esterase capable of hydrolysing the methyl ester of benzylpenicillin has been found in guinea-pig extracts. It has not been possible to hydrolyse esters of penicillin by chemical means without appreciable losses of activity, even under the mildest conditions.

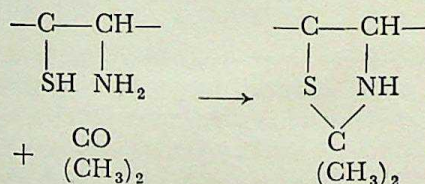
THE THREE FUNDAMENTAL COMPONENTS OF THE PENICILLIN MOLECULE

The penicillin molecule is built up of three fundamental components into which it can be broken down with the participation of two molecules of water. These are the thiol-amino-acid β -thiolvaline, also termed penicillamine (which is a constituent common to all penicillins); an

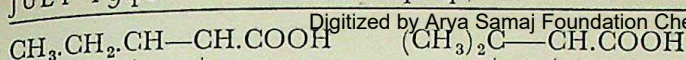
acylated aminoacetaldehyde termed penilloaldehyde (the acyl group of which differs in the different penicillins); and one molecule of carbon dioxide.

PENICILLAMINE

This substance was the first degradation product of penicillin to be obtained in the crystalline state [5]. It can be precipitated, in the form of its complex with mercuric chloride, from acid hydrolysates of the penicillins or from solutions of alkali-inactivated penicillins. It can be obtained in the form of its crystalline hydrochloride after decomposition of the mercuric chloride complex with hydrogen sulphide. It has the molecular formula $C_5H_{11}O_2NS$, and is thus the part of the penicillin molecule containing the sulphur atom. It gives strong colour reactions for free $-SH$ with sodium nitroprusside or ferric chloride, and its nitrogen is present as α -amino nitrogen, which can be determined according to the method of van Slyke. When the hydrochloride of penicillamine is dissolved in acetone and the solution is evaporated to dryness a crystalline derivative is obtained which contains no free $-SH$ or $-NH_2$ group and has the molecular composition $C_8H_{15}O_2NS$. On heating with dilute acid, acetone is liberated and the hydrochloride of penicillamine regenerated. This suggested that the $-SH$ and $-NH_2$ groups in penicillamine were next to each other and had reacted with acetone to give a thiazolidine:



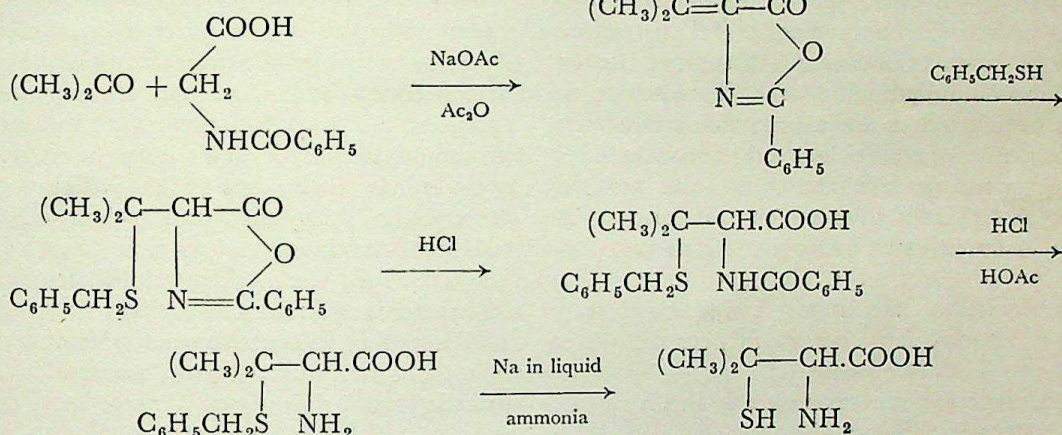
On oxidation with bromine water penicillamine hydrochloride was transformed into a crystalline amino-acid with the molecular formula $C_5H_{11}O_6NS$; this is the corresponding sulphonic acid. The electrometric titration curve of penicillamine showed three titratable centres, with pK values of 1.8, 7.9, and 10.4, corresponding to the carboxyl, amino, and thiol groups respectively. Of the two isomeric formulae possible for penicillamine (II and III), II seemed improbable because C-methyl determinations according to the method of Kuhn and Roth gave values of only a fraction of one molecule. This finding was in agreement with structure III, which contains a *gem*-dimethyl group:



II

III

The correctness of structure III for penicillamine was proved by synthesis. The first synthesis of *dl*-penicillamine was achieved at Oxford (Abraham, Baker, Chain, Cornforth, and Robinson, 1943) and consisted in the addition of benzyl mercaptan to 2-phenyl-4-*isopropylidene*-oxazolone in the presence of sodium methoxide, following the method of Carter, Stevens, and Ney (1941) for the synthesis of methyl cysteine. The steps involved in the synthesis are indicated by the following scheme:



to reduction. Neither *d*- nor *l*-penicillamine, nor their disulphides, are attacked by enzymes occurring in animal tissues.

THE PENILLOALDEHYDES

While penicillamine is a constituent common to all penicillins, each penicillin gives rise to a different penilloaldehyde. The penilloaldehydes can be obtained in the form of their 2,4-dinitrophenylhydrazones after hydrolysis of the penicillins by dilute acid at 100° C and precipitation of penicillamine with mercuric chloride. They can also be obtained by decomposition with mercuric chloride of the penicilloic acids, which are the products of alkaline inactivation of the

Later several other methods of synthesis of *dl*-penicillamine were developed. The resolution of *dl*-penicillamine can be achieved by the fractionation of the brucine salt of the N-formyl derivative. Natural penicillamine belongs to the *d*-series. This was first concluded from its optical behaviour and that of its *isopropylidene* derivative, and was finally proved by treatment of the phenylureido derivative with Raney nickel; this led to the phenylureido derivative of *d*-valine (Merck group, October 1943). Penicillamine is another example of an amino-acid possessing the 'unnatural' *d*-configuration occurring in metabolic products of micro-organisms. It will be recalled that the antibacterial polypeptides gramicidin and tyrocidine, and the antigen from *B. mesentericus*, contain amino-acids of the unnatural configuration. Penicillamine is a new amino-acid which up to the present time has not been found in any other biological material. It is more soluble in water than cysteine and its disulphide is very resistant

penicillins. The first penilloaldehyde to be isolated was derived from Δ^2 -pentenylpenicillin, prepared from surface cultures, with which the British investigators had been working. Its structure was established as follows (Oxford workers, September–November 1943). The elementary analysis of the dimedone derivative and determination of its molecular weight by crystallographic X-ray measurements indicated that the molecular formula of the penilloaldehyde was $\text{C}_8\text{H}_{13}\text{O}_2\text{N}$. Oxidation with silver oxide gave an acid $\text{C}_8\text{H}_{13}\text{O}_3\text{N}$. After hydrolysis with 10 per cent. hydrochloric acid or sodium hydroxide a high proportion of the nitrogen of this acid was present as α -amino nitrogen, reacting in the van Slyke determination. Hence it was concluded that it contained a peptide linkage. Meanwhile American chemists had isolated in the crystalline form the sodium salt of the penicillin with which they had been working, and established its molecular formula as $\text{C}_{16}\text{H}_{18}\text{O}_4\text{N}_2\text{S}$. The American

penicillin, like the British one, yielded penicillamine on acid hydrolysis. It became known that phenylacetic acid could be isolated from acid hydrolysates of the American penicillin. This easily recognizable substance could never be detected among the hydrolytic breakdown products of the British penicillin, and this fact established conclusively that the two penicillins were chemically different. As both penicillins yielded penicillamine, the difference in their structure could only be located in the penilloaldehyde part of the molecule. On the basis of the molecular formula for the American penicillin it was surmised that it would yield a penilloaldehyde of the formula $C_{10}H_{11}O_2N$ which, on oxidation with silver oxide, would give an acid $C_{10}H_{11}O_3N$. Assuming that this acid contained phenylacetic acid and a peptide linkage, its structure could only be that of phenylacetyl-glycine, and the structure of the corresponding penilloaldehyde that of phenylacetyl-aminoacetaldehyde. This being so, it was deduced that the acid deriving from the British penilloaldehyde had the structure of a hexenoylaminoacetaldehyde. This was proved by the isolation of glycine (in the form of its naphthalenesulphonyl derivative) from acid hydrolysates of the acid $C_8H_{13}O_3N$; only a few milligrams were obtained, but the specimen was identified by X-ray crystallographic measurements.

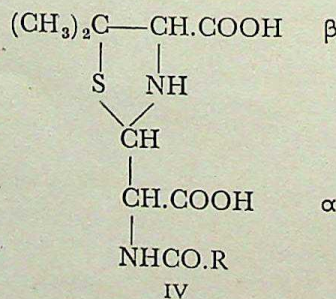
The structure of the hexenoic acid in the British penilloaldehyde was established as follows. The isolation of caproic acid, in the form of its *p*-bromophenyl-phenacyl derivative, from acid hydrolysates of catalytically reduced British penicillin showed that it possessed a straight carbon chain (Imperial College workers, October 1943). The double bond was located in the β - γ -position by oxidation with cold permanganate, which gave propional. Thus the structure of the British penilloaldehyde was that of β - γ -pentenylaminoacetaldehyde. The acetal of this aldehyde was synthesized from aminoacetal and β - γ -hexenoyl chloride. It gives a 2,4-dinitrophenylhydrazone identical with that obtained from the British penicillin. The acetal of the American penilloaldehyde was synthesized in a similar manner from phenylacetyl chloride and aminoacetal.

Later, other penilloaldehydes were isolated from natural penicillins, for example *p*-hydroxy-phenylacetyl-aminoacetaldehyde from *p*-hydroxy-benzylpenicillin (penicillin X) and *n*-caprylylaminoacetaldehyde from *n*-heptylpenicillin (penicillin K).

The penicillins contain one free carboxyl group and one in bound form. When they are heated in acid solution at 80–100° C. for short periods decarboxylation occurs. Decarboxylation also takes place when the products of alkali inactivation are treated with mercuric chloride. When the methyl ester of Δ^2 -pentenylpenicillin was treated with mercuric chloride decarboxylation took place and the methyl ester of *d*-penicillamine could be isolated from the reaction product. This showed that the carbon dioxide derived from the bound carboxyl group and not from the free carboxyl group belonging to the penicillamine fragment of the penicillin molecule (I.C.I. workers, 1944).

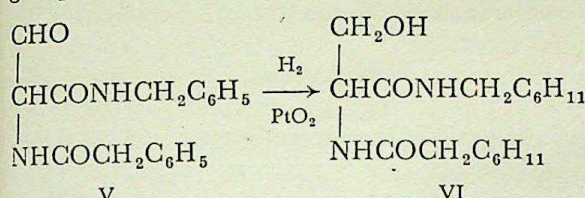
THE STRUCTURE OF THE PENICILLOATES

The products of alkali inactivation of the penicillins, termed penicilloates, can be decomposed by mercuric chloride into penicillamine, penilloaldehydes, and carbon dioxide. They contain no free amino or sulphhydryl group and give no precipitation with 2,4-dinitrophenylhydrazine before the addition of mercuric chloride. From this it was concluded that penicillamine and the penilloaldehyde were linked together in the penicilloic acid molecule in a thiazolidine ring. The tendency of penicillamine readily to form thiazolidines with aldehydes or ketones had been noticed at an early stage of the investigations (see above), and fission by mercuric chloride is a characteristic reaction of thiazolidines. The most likely position of the labile carboxyl group which appeared as carbon dioxide after treatment of the penicilloates with mercuric chloride was β to the potential aldehyde group of the penilloaldehyde. It was therefore concluded that the penicilloic acids were thiazolidines of the structure IV:



This was proved as follows. It had been found that treatment of the American penicillin with benzylamine led to the formation of a crystalline, biologically inactive, product of the composition

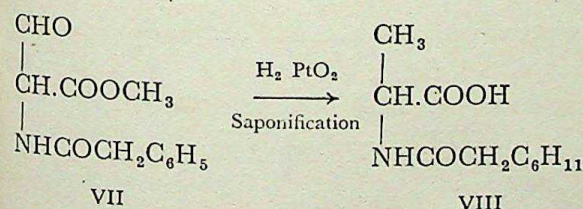
$C_{30}H_{36}N_4O_4S \cdot H_2O$ (Northern Regional Research Laboratory, 1943). Decomposition of this substance with mercuric chloride gave the mercuric chloride complex of penicillamine and the supernatant solution yielded a 2,4-dinitrophenylhydrazone. The structure of the corresponding aldehyde was proved to be V by catalytic reduction with platinum oxide, which gave the cyclohexylamide of N-cyclohexylacetylserine, VI (Merck group, November 1943):



The aldehydo-acid $\text{CHO} \cdot \text{CH} \cdot \text{COOH}$ which,
 $\text{NHCO} \cdot \text{R}$

of course, is not stable in the form of the free acid but can be obtained in the form of its esters, amides, or other derivatives, has been termed penaldic acid, and the penaldic acids deriving from different penicillins are differentiated in the same way as the penicillins by prefixes indicating the nature of the group R.

Additional proof for the structure of the penaldic acids and of the penicilloates was obtained by degradation of the product of methanol inactivation of benzylpenicillin. On decomposition with mercuric chloride the methyl ester of an aldehydic acid was liberated which could be converted by catalytic hydrogenation into N-cyclohexylacetylalanine (VIII) and therefore had structure VII:



Thus it was clear that the penicilloates were thiazolidines formed from penicillamine and penaldates. Of the two carboxyl groups of the penicilloic acids the one belonging to penicillamine is termed β , and the other, belonging to penaldic acid, α . With the elucidation of the structure of the penicilloic acids the mechanism of a number of inactivation reactions of the penicillins became clear. As has already been stated, the action of primary amines on the penicillins leads to the formation of α -monoamides of the

penicilloates and the action of primary alcohols to the formation of α -monoesters. The latter reaction is catalysed by metal ions, particularly copper, zinc, and tin, and can be greatly retarded by the addition of dimercaptopropanol (British Anti-Lewisite, BAL). In its presence the penicillins are stable in primary alcohols at 37°C for at least 24 hours [8]. The action of metal ions such as copper, zinc, or cadmium on penicillin salts in aqueous solution also leads to the formation of penicilloates. It is thus possible to carry out a stepwise saponification of diesters of the penicilloates.

Penicilloates are also formed from the penicillins under the influence of the enzyme penicillinase. The action of hydrazine on the penicillins leads to the formation of α -hydrazides, that of hydroxylamine to the formation of α -hydroxamic acids; cysteine, which inactivates the penicillins in neutral aqueous solution, reacts with the sulphhydryl group (Squibb workers). The α -hydrazides of the penicilloates readily undergo ring closure; 4-phenylacetamino-5-pyrazolone is formed from the α -hydrazide of benzylpenicilloic acid. The action of acetic acid on the penicillins in the form of their free acids leads to the formation of N-acetylpenicilloates (Squibb workers, 1944). The penicilloates deriving from *d*-penicillamine can occur in four stereoisomeric forms, and all of them have been isolated (Merck group, 1944). They differ widely in their melting-points and specific rotations. They are designated as α , β , γ , and δ -forms. The α , β , and γ forms can be isolated from mutarotated synthetic benzylpenicilloates. The δ -form, which is laevorotatory, is obtained by the action of copper sulphate on benzylpenicillin (Squibb workers, 1944).

The penicilloates can readily be synthesized by condensation of penicillamine or its esters with penaldates. Numerous penicilloates and their N-acyl derivatives have been prepared by this method.

THE STRUCTURE OF THE PENILLIC ACIDS AND PENILLAMINES

The products formed when the penicillins are inactivated in aqueous solution at acid pH have been termed penillic acids. The first penillic acid to be isolated was derived from Δ^2 -pentenylpenicillin obtained from British surface cultures (Duffin and Smith, 1943). The penillic acids have a great power of crystallization. They are insoluble in organic solvents and only slightly soluble in water. They have a higher specific rotation than the penicillins and show a characteristic ultra-violet absorption at about $2,730 \text{ \AA}$.

Elementary analysis shows that they are isomeric with the penicillins. When treated with mercuric chloride they are decarboxylated and transformed into the hydrochlorides of bases termed penicillamines. These are stable substances resisting treatment with hot acid or alkali. They give the colour reaction for a free sulphhydryl group but do not possess an α -amino group. Electrometric titration shows three titratable centres, one corresponding to a carboxyl group, one to a basic group, and one to the sulphhydryl group. Oxidation with bromine leads to the formation of penicillaminic acid, and on treatment with 2,4-dinitrophenylhydrazine the osazone of glyoxal is obtained. As the sequence of the atoms in the penilloaldehyde moiety is fixed, the only possible structure for the penillamines which will conform with the above facts is the imidazole structure IX (Imperial College workers, 1943). The penillic acids, which contain an additional molecule of carbon dioxide and no free sulphhydryl group, were assigned the imidazoline structure X (Oxford workers, 1943). On treatment with cold alkali or on refluxing in methanol the penillic acids undergo isomerization to the isopenillic acids. These contain a free sulphhydryl group and were assigned the structure XI (Oxford workers, 1944):

The penillamines have also been synthesized by different methods.

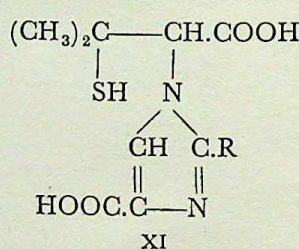
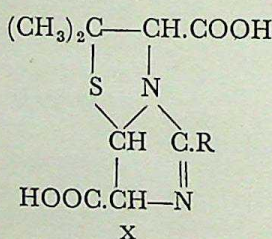
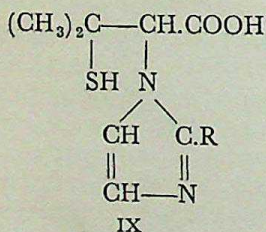
STRUCTURAL FORMULAE FOR THE PENICILLIN MOLECULE

In devising structural formulae for the penicillin molecule the following facts had to be considered:

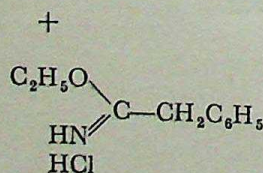
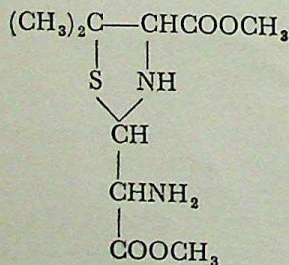
1. The penicillins are built up from penicillamine, penilloaldehydes, and one molecule of carbon dioxide, with the elimination of two molecules of water.
2. Both nitrogen atoms must be present in the non-basic state.
3. The penicillins undergo isomerization to imidazoline derivatives under very mild conditions.

Numerous formulae for the penicillin molecule can be constructed by joining its three components with the elimination of two molecules of water. Many of these possibilities can be discarded because they are in obvious disagreement with the physical and chemical properties of penicillin.

If the penicilloic acids are considered to be formed from the penicillins by direct hydrolysis, without the occurrence of an intramolecular

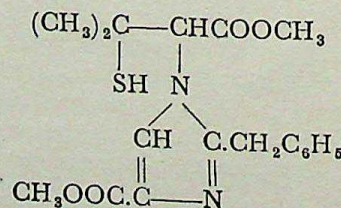
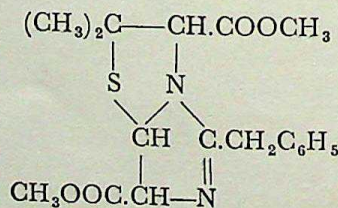


Benzylpenillic acid and benzylisopenillic acid have been synthesized, as outlined in the following schemes (Merck group, 1944):



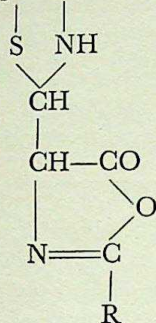
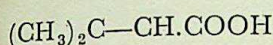
Ethylene dichloride

Tertiary butanol

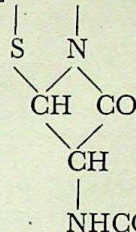
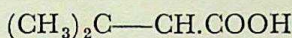


rearrangement, penicillin formulae can be constructed by eliminating from the penicilloic acids one molecule of water.

The first formulae suggested were the thiazolidine-oxazolone structure XII and the β -lactam structure I (Oxford workers, October 1943):



XII



I

The former, containing the reactive oxazolone ring, appeared to explain some of the characteristic reactions of the penicillins, i.e. the reaction with alkali to give penicilloates, the reaction with primary alcohols and amines to give α -esters or α -amides of the penicilloates, and the isomerization to the penillic acids. Its main difficulty lay in the imino group of the thiazolidine ring; this

would have been expected to exhibit basic properties, whereas in fact the penicillins did not contain a basic group. The β -lactam structure was suggested in order to overcome this difficulty. In it both nitrogen atoms are present in the form of non-basic groups.

The thiazolidine-oxazolone structure was suggested independently by the Merck group as the most likely expression of the penicillin molecule, though the β -lactam structure was also mentioned by them as a theoretical possibility. It was the structure favoured by the majority of workers until early in 1945. By that time evidence began to accumulate which was difficult to reconcile with it but which was compatible with the β -lactam structure. In order to arrive at a conclusive decision between the two structures investigations were carried out in two directions. On the one hand, model compounds of the different ring systems postulated to be present in the two structures, i.e. thiazolidines, oxazolones, and β -lactams, were synthesized and their properties compared with those of the penicillins. On the other hand, further degradation studies of the penicillins were conducted, and these led to the preparation of several new degradation products. The results of these two lines of work will be considered next.

(To be concluded)

REFERENCES

- [1] FLEMING, A. 'On the Antibacterial Action of Cultures of a *Penicillium*, with Special Reference to their Use in the Isolation of *B. influenzae*,' *Brit. J. Exp. Path.*, 10, 226, 1929.
- [2] CLUTTERBUCK, P. W., LOVELL, R., and RAISTRICK, H. 'Studies in the Biochemistry of Microorganisms. XXVI: The Formation from Glucose by Members of the *Penicillium chrysogenum* Series of a Pigment, an Alkali-soluble Protein, and Penicillin—the Antibacterial Substance of Fleming,' *Biochem. J.*, 26, 1907, 1932.
- [3] CHAIN, E., FLOREY, H. W., GARDNER, A. D., HEATLEY, N. G., JENNINGS, M. A., ORR-EWING, J., and SANDERS, A. G. 'Penicillin as a Chemotherapeutic Agent,' *Lancet*, ii, 226, 1940.
- [4] ABRAHAM, E. P., CHAIN, E., FLETCHER, C. M., FLOREY, H. W., GARDNER, A. D., HEATLEY, N. G., and JENNINGS, M. A. 'Further Observations on Penicillin,' *Lancet*, ii, 177, 1941.
- [5] ABRAHAM, E. P., BAKER, W., CHAIN, E., and ROBINSON, R. 'Penicillamine, a Characteristic Degradation Product of Penicillin,' *Nature*, 151, 107, 1943.
- [6] CHAIN, E., and FLOREY, H. W. 'Penicillin,' *Endeavour*, 3, 3, 1944; 'The Discovery of the Chemotherapeutic Properties of Penicillin,' *British Medical Bulletin*, 2, 5, 1944.
- [7] CHAIN, E. 'The Chemistry of the Penicillins,' *Ann. Rev. Biochem.* (in press).
- [8] CHAIN, E., and PHILPOT, F. J. 'The Catalytic Effect of Metal Ions on the Alcoholysis of the Penicillins,' *Arch. Biochem.* (in press).

Lazzaro Spallanzani: founder of experimental physiology

E. TORTONESE

Biological inquiries developed rapidly in the eighteenth century. Among the greatest of the scientists responsible for this progress was Lazzaro Spallanzani, an Italian priest and man of science who taught natural history in the University of Pavia for thirty years. He made wide use of the experimental method and in a long series of researches achieved most valuable results, especially in the fields of physiology and general biology. Important contributions to other branches of natural history are also to be found in his voluminous writings.

During the eighteenth century great advances were made in various branches of science, thanks to important contributions from several European countries. New fields of inquiry were disclosed, and the foundations were laid for many later achievements. Methods of research were improved, and both experiment and observation became increasingly fruitful. As far as biology is concerned, men of several different nationalities were responsible for the progress accomplished during the century: Linnæus in Sweden, von Haller in Germany, Buffon in France, etc. In Italy, too, several workers, particularly Spallanzani, Cetti, Olivi, and Cestoni, well deserved the title of biologists, though that term was not suggested until three years after Spallanzani's death. The name of Lazzaro Spallanzani (1729-99) will always find a place of honour in the history of science. To him we owe a series of very careful investigations of both the structure and the life-histories of animals. He made also several important observations in various other fields of natural history.

Spallanzani, the son of a jurist, was born at Scandiano, near Modena in northern Italy, on 10th January, 1729. At the age of 15 he was sent to the Jesuit college at Reggio, but soon (1747) went as a student of law to the University of Bologna. Here his cousin Laura Bassi was professor of physics; under her influence and with her help the young man became entirely engaged in scientific studies, in which he felt a deep and increasing interest. His textbooks of law were soon abandoned, while those by Vallisnieri (figure 1) and other naturalists were carefully perused. He was ordained as a priest, and in 1755 came back to Reggio to teach logic in the college there. He had a sound knowledge of classical languages and taught Greek and metaphysics. Two years later he

was appointed professor of physics and mathematics in the university in the same town. In 1763 he went to Modena as a teacher of mathematics and Greek in S. Carlo College and of physics and philosophy in the university.

The greater part of Spallanzani's professorial life was, however, spent in Pavia, where he was professor in the university from 1769 until his death on 12th February, 1799. With his arrival, official classes in zoology began in that famous university, to which a new endowment had been given by Queen Maria Theresa. From 1775 onwards the scientific collections, books, and instruments began to be properly arranged.

It is not easy to give briefly an adequate idea of the amount of work done by Spallanzani, but even a short article such as this can show how he contributed to the advancement of science by a series of first-class experiments and observations. He was interested in a variety of subjects and cannot be said to have been a pure biologist: physics, geology, and mineralogy also largely occupied his attention. His name is, however, particularly closely connected with the development of experimental physiology, of which he may rightly be considered the founder. It was in this field that his main discoveries were made. A number of fundamental biological problems were tackled by Spallanzani, who successfully applied the experimental method—the method primarily responsible for the many superb achievements of modern science. He followed the example of another great Italian naturalist, Antonio Vallisnieri (1661-1730), who had strongly advised all 'philosophers' to carry out experiments and observations again and again, and never to tire of collecting and comparing them in order to find out the truth.

In ancient and medieval times there was a firm belief in spontaneous generation or the origin of

organisms from inanimate matter. Digital Library, Argy. Sanyal Foundation Chennai and eGangotri

action of sunshine on mud. A well-known Italian poet, physician, and naturalist, Francesco Redi (1626-96) of Arezzo (Tuscany), showed that the spontaneous generation of insects from dead animals did not occur; if the flesh of the animal were protected, no grubs or maggots appeared in it. Spallanzani made other experiments to disprove the possibility of spontaneous generation (finally disposed of by Pasteur in the following century), and demonstrated that no animalcules developed in vegetable infusions which had been boiled and were kept in properly closed vessels. Infusoria, like other organisms, can develop only from pre-existing individuals of the same kind. This subject is dealt with in his *Essay on Microscopical Observations concerning the System of Generation by Needham and Buffon* (Modena, 1765), which deservedly ranks among his most famous works. Its publication marks a definite victory over such opponents as Needham and Buffon.

It is evident from these researches that the reproductive processes of living things had an outstanding interest for Spallanzani. After close investigations he was able to advance partial explanations of several of them. In his *Prodrome to a Work concerning the Reproduction of Animals* (Modena, 1768), to which great attention was paid by contemporary students, he describes the regenerative power of certain animals.

Several years later (1777-82) he carried out a number of classic experiments on fertilization. Fertilization had been previously attributed to an *aura seminalis* which was responsible for the subsequent development of the eggs. This fanciful idea was accepted even after the discovery of spermatozoa in the seventeenth century (*Animalcula seminalia* were first observed in Holland by Hamm in 1677, and were so named by Leeuwenhoek). Spallanzani showed that fertilization can occur only if the spermatid fluid actually comes into contact with the ovum; he was able to fertilize artificially not only the ova of different amphibians and of the silkworm, but even those of a bitch. He described these achievements in *Prodrome of the New Italian Encyclopaedia* (Siena, 1779). He failed, however, to recognize the spermatozoa as the true activating elements and attributed such a function to the liquid medium. A little more than forty years later Prevost and Dumas (1824) proved that eggs are fertilized by the small cells or animalcules existing in the spermatid fluid and that the latter becomes quite inactive if filtered.

A book (figure 2) which secured continuing fame



FIGURE 1 - Antonio Vallisneri, the great Italian naturalist in whose books Spallanzani found an example and an incentive. He was born near Modena in 1661 and died at Padua in 1730.



FIGURE 2 - Title page of Spallanzani's treatise on animal and vegetable physics.

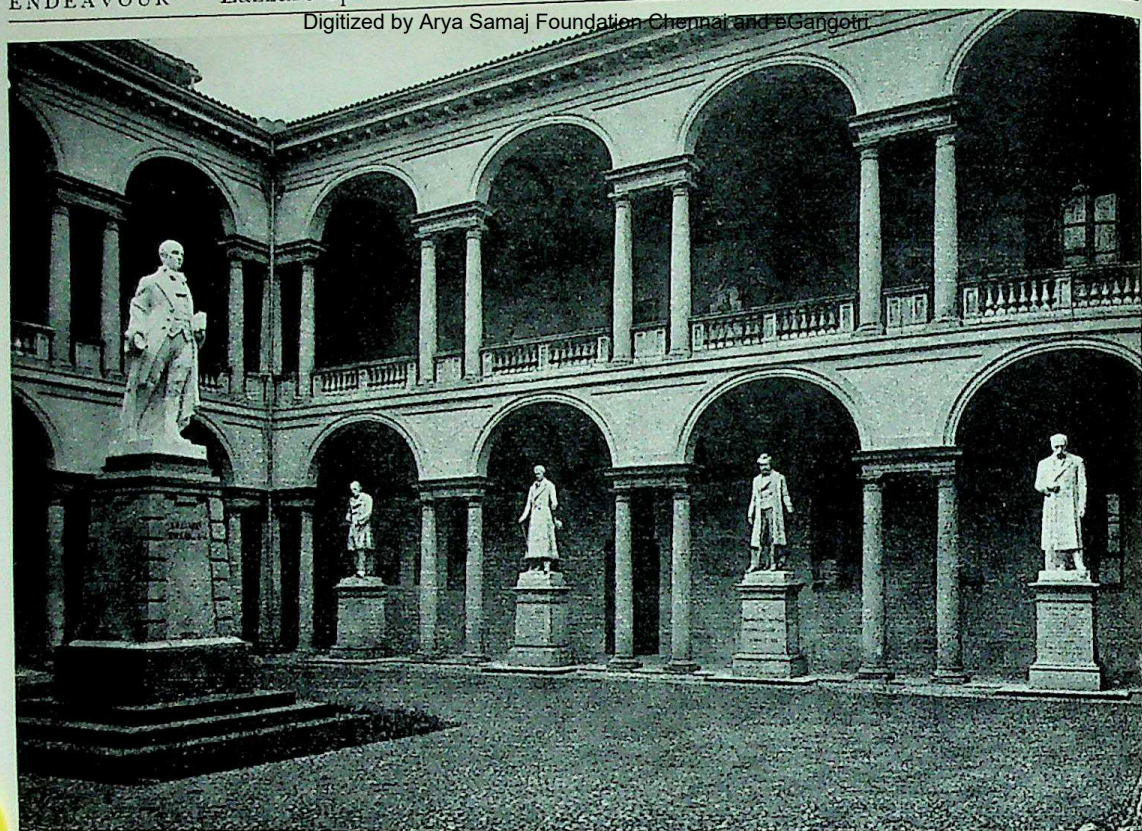


FIGURE 3 - The courtyard of the University of Pavia, with the Spallanzani monument on the left.

to Spallanzani is entitled *Dissertations on Animal and Vegetable Physics* (Modena, 1780). Its first volume deals with digestion and the second one with reproduction. In both of them several ideas commonly held in that epoch are criticized and modified. It is well known that the history of embryology during the eighteenth century is characterized by the controversy between those who believed in the preformation of the new individual in the germ (preformists), and those who maintained that its formation is completed after fertilization (epigenists). While G. F. Wolff, his great German contemporary, was an epigenist, Spallanzani strongly supported the preformist view. He stated that the embryo is completely formed in the egg and that 'the presence of embryos in females before fertilization is one of the most general laws of nature.' This opinion was strengthened by a series of observations on amphibians, which convinced him that the so-called eggs of frogs are not really eggs at all, but small tadpoles with all their parts already in existence and simply awaiting further development.

The reproduction of plants proved to be another

attractive field for research. Spallanzani dealt with it in about a hundred pages of the second volume of the 'Dissertations,' describing what he was able to observe in several species (*Genista*, pea, cucumber, hemp, etc.) and, applying the preformist principle to these organisms also, he maintained that seeds exist before fertilization and that the pollen is a reproductive agent for some kinds of plants, while for others it is unnecessary.

From the six chapters composing the first volume of the book mentioned above it appears that Spallanzani correctly interpreted the process of digestion, about which there had been much controversy. For both Galen and Paracelsus digestion was a 'cooking,' caused by the heat of the stomach, while for Sylvius and van Helmont it was a fermentation. The great French physicist and naturalist R. A. Ferchauld de Réaumur (1683-1757) caused some buzzards to swallow little perforated glass tubes containing small pieces of meat; the perforations were intended to allow the gastric juices to enter the tubes. He then killed the buzzards, extracted the tubes and examined the pieces of meat they had contained. The

appearance of the meat indicated that it had been subjected to a kind of solvent action. This experiment satisfied him that digestion was due to a solvent substance rather than to any mechanical action. Spallanzani agreed with Réaumur and advanced a fuller explanation of the function of the digestive juices. He showed conclusively that the latter are the active agents in digestion, and that their effects are more or less rapid according to the nature of the food ingested. He showed that the juices have antiseptic properties. He stated, too, that the digestive process is quite different from fermentation and that sometimes the alimentary tract exerts an important mechanical action, as, for example, in the gizzards of birds. In 1777 he repeated in public the famous experiments performed in Florence by members of the Accademia del Cimento, demonstrating the remarkable strength of hens and ducks, which will in a few hours grind small spheres of glass to powder in their gizzards.

Spallanzani was led to his conclusions by experiments on birds, reptiles, dogs, and other animals, together with an investigation of the digestive process *in vitro*. Some objections against these arguments were raised by J. Hunter, the leading English anatomist and physiologist of his time, but they were easily refuted.

Spallanzani's high qualities as experimentalist are evident also from his work on the circulation of the blood and on respiration. He was the first to observe that in a chick embryo the blood passes from the arteries to the veins through tiny vessels called capillaries. He wrote two papers on the circulation: *On the Action of the Heart on Blood-vessels* (Modena, 1768) and *On the Phenomena of Circulation observed in the Universal Course of Vessels*,

In his study of the respiratory process he proved that exchange of gases through the skin (cutaneous respiration) plays an important part in the life of amphibians. He confirmed the hypothesis of the internal respiration of tissues that had been proposed by the mathematician Lagrange of Turin (1736-1813). It was therefore well established that processes of combustion are going on without interruption in every organ and tissue. These subjects are discussed in a posthumous paper, *Memoirs on Respiration* (Milan, 1803).

This brief enumeration of Spallanzani's main achievements in the strictly physiological field is by no means complete, for we are indebted to him for a series of other valuable observations which are primarily of zoological interest. His well-known experiments on the senses of bats, to which reference has already been made in these pages (see ENDEAVOUR, 1947, 6, 36), are typical. He blinded some of the animals and found that afterwards they could fly in a room and avoid all obstacles, even such slight ones as silken threads stretched across their path. He studied the zoology of sponges, the electrical powers of rays (*Torpedo*) the reproduction of eels, the curious habits of hermit crabs, and the life of some aquatic animalcules (Rotifers, Tardigrads), which can resist desiccation even for long periods.

Spallanzani therefore occupies an important place in the history of zoology. In this connection we must remember his travels, the reports of which were published partly by himself and partly after his death. His journeys greatly widened the field of his observations and enabled him to present many specimens to the museum of the University of Pavia. Both in Italy and abroad he collected

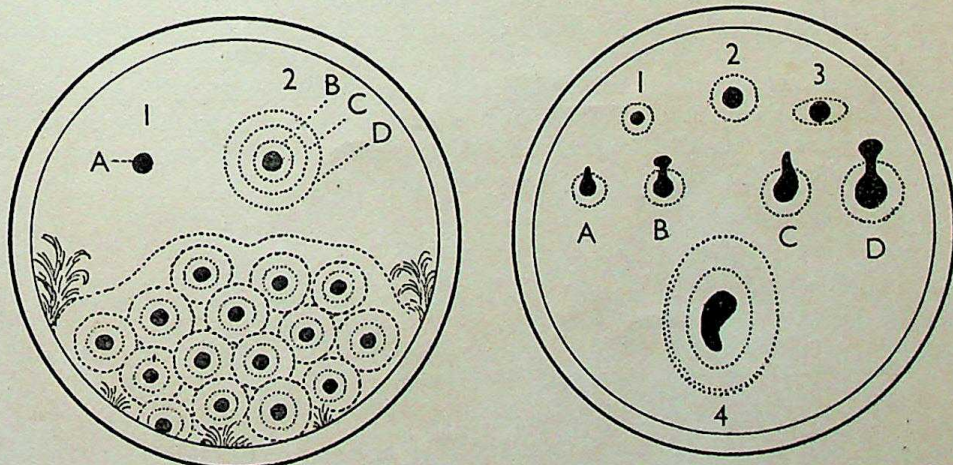


FIGURE 4 - Frogs' eggs and their early stages of development, as figured by Spallanzani in his 'Dissertations' (1780).

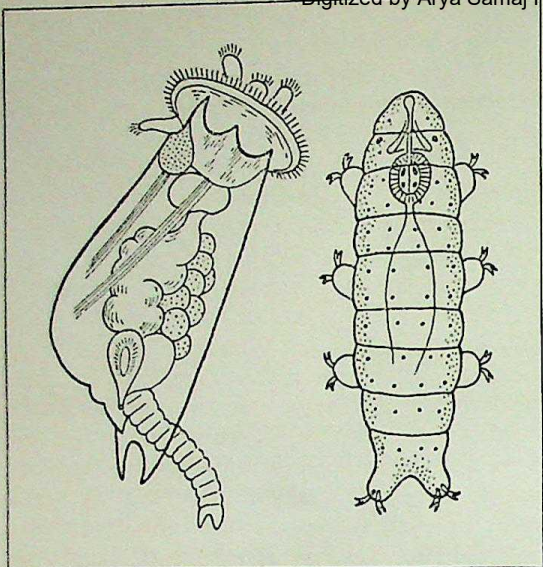


FIGURE 5 — Small animals whose endurance to desiccation was noticed by Spallanzani: a Rotifer (*Brachionus*) (left) and Tardigrad (*Macrobiotus*) (right). Tardigrads were so named by him in 1776 on account of their slow movements.

animals as well as minerals and rocks, and he wrote field notes on zoology, mineralogy, and physics. The characteristics of people in various countries and their customs and habits were also noted.

He visited Switzerland (1779) and several parts of the Mediterranean shores (Ligurian, Adriatic, etc. (1781-83)), making valuable observations on marine biology. In 1785 he was invited to go to Padua, where a professor of natural history was needed, but he refused not only because the queen, Maria Theresa, granted him double pay and permission to leave for a journey to Eastern regions, but also because of his genuine affection for Pavia. In 1785 he went to Constantinople, accompanying the ambassador sent there by the republic of Venice, and visited parts of Asia Minor, the Balkans, and Germany; in Vienna he received high honours from the emperor of Austria. His impressions are described in the book

(1788). In another book, *Travels to Sicily and Some Parts of the Apennines* (Pavia, 1792-7), are embodied all the notes collected during a long trip across the Italian peninsula as far as Sicily. Spallanzani climbed Vesuvius and Etna and paid visits to the Campi Flegrei near Naples and Colli Euganei near Padua. His memoirs concern not only mineralogy and geology but also many biological topics, such as the phosphorescence of jelly-fishes, sundry species of birds, the eel-fisheries at Comacchio, and so on.

Unlike many men of science, Spallanzani was a very good writer; his style is not only simple and clear but elegant and convincing, avoiding any rhetorical ornament. He corresponded with the Swiss naturalist Charles Bonnet in Geneva (1720-93), a very keen investigator of living organisms and the discoverer of parthenogenesis in aphids or plant-lice. Bonnet highly appreciated the work of his Italian friend and shared his views on many phenomena, saying that Spallanzani alone had discovered in a few years more than most famous European academies did in many. We owe to Spallanzani a translation of Bonnet's *Contemplations de la Nature* (Modena, 1769), some parts of which are included in his 'Dissertations' together with letters between these two scientists.

Spallanzani was a member of many academies and scientific societies, both Italian (Bologna, Siena) and foreign (London, Stockholm, Berlin, Montpellier). He used to perform all his duties with the utmost keenness and precision. He did not live a secluded life in his laboratory, but was glad to announce in public dissertations the main results of the researches he was carrying on. Spallanzani did not, of course, escape jealousy and slander from his contemporaries, but the quality of his work and his uprightness of character were always a sufficient answer to his critics. In his private and public life and in his scientific work he was never fettered by prejudice and tradition and never failed to reason with an open and unbiased mind.

REFERENCES

- CARUS, V. *Histoire de la Zoologie* (Paris, 1880).
 DAMPIER, W. C. *A Shorter History of Science* (Cambridge, 1944).
Encyclopaedia Britannica, 1929, vol. 21, p. 147.
 MONTALENTI, G. 'Lazzaro Spallanzani,' *Nuova Antol.* (Rome, 1929).
 Idem. 'Spallanzani, L.' *Encicl. Ital.*, 1936, vol. xxxii, p. 299.
 SPALLANZANI, L. *Le Opere* (1932).

The theory that the coloration of animals is of functional and evolutionary significance is now generally accepted, though many extravagant claims once made for it have had to be rejected. Certain patterns of colour may undoubtedly be of value to animals in protecting them from their enemies and allowing them to approach their victims without alarming them. In this article the author discusses and illustrates the main types of animal camouflage.

It is the fate of most scientific theories to pass through three stages of development. When first propounded, a new theory often receives an enthusiastic and rather uncritical welcome. Then, as the exaggerations of some of its more enthusiastic disciples become apparent, there follows a period of hypercriticism, in which the basic idea tends to be rejected because some of the applications suggested are shown to be unsound. Lastly comes a renewed and critical appraisal, from which a sound theory emerges as firmly established within known limits, but an unsound theory vanishes from the scene.

So it has been with the belief that animal coloration is in many cases adapted to protect the wearer, or to aid in ambush and capture of prey. Some of those who followed the pioneer work of the late Sir Edward Poulton put forward suggestions so far-fetched that, along with the patently foolish, much of the more solid theory came to be rejected. In realizing the folly of the suggestion that the colour of the flamingo concealed it during flight across a sunset sky, many zoologists failed to appreciate the perfection with which the plumage of the snipe, *Capella gallinago* (figure 8), conceals the bird in its haunts of tangled marsh herbage, and it was at times asserted that all coloration was a mere by-product of metabolism, without functional or evolutionary significance. Of recent years a sober revaluation of the available facts has shown that animal coloration often serves to conceal or to mislead, and the reality and effectiveness of animal camouflage are not now disputed.

The word camouflage has often been taken as synonymous with protective concealment, but in fact any mechanism which baffles observation by another creature must be regarded as a camouflage device, without reference to the defensive or aggressive nature of its function. Needless to say, the same colouring or structure may often serve a dual purpose, making an animal more difficult

for its enemies to discover and its victims to avoid.

A concealing device may be of two kinds. There may be special resemblance to a particular background, such as is shown by phasmids (stick insects, figure 4), leaf insects (*Phyllium pulchrifolium*, figure 3), and tree-frogs (*Hyla arborea*, figure 5), in which main outline, details of structure, basic coloration, and niceties of pattern all contribute to simulation of the habitat of the wearer. Special resemblances are most frequently found in comparatively small and sedentary animals—insects, crabs, and some small weed-haunting fishes—in which a single tree, a patch of tangle, or a mat of floating weed provides a range sufficient for the creatures' needs.

Larger and more active creatures do not usually show special resemblances, for it is clear that the more exactly combinations of structure, pattern, and proportion give resemblance to one kind of background, e.g. a particular leaf, frond, or flower, the wider must be the difference from other backgrounds. The most interesting part of the study of animal concealment is that of the mechanisms by which animals obtain a degree of inconspicuousness in a wide variety of habitats. It is scarcely necessary to say that no scheme of coloration could be suitable for all backgrounds, but the more active forest animals are so patterned that they are inconspicuous in forests and not in one tree of that forest. Similarly the littoral creatures are adapted to the shore in general, and not to the shelter of a particular species of alga.

It should be noticed that it is inconspicuousness, not invisibility, which is required. The function of camouflage is not to prevent the wearer from being seen by its enemy or victim, but to prevent recognition. The mere biochemical processes of vision are unimportant: what must be prevented is the integration of the units of variously illuminated colour, which are the raw materials of perception, into a coherent whole having (to use Dr E. S.

Russell's term) valence for the beholder. It matters not at all that one or many parts of an animal be seen, so long as they are not recognized as belonging to that animal. For example, the long cream streak on *Psammophis subtaeniatus* (figure 6) is in itself conspicuous, but the eye of the beholder tends to follow it and to be diverted from the cylindrical form of the snake itself.

The characteristic outlines of any animal may be concealed by structural alterations or by a pattern which deflects attention from underlying structure. In the comma butterfly *Polygonia c.-album* (figure 7), the outer edges of both fore and hind wings show fretted outlines very different from the usual smooth curves of a butterfly's wings, and it will be noted that, on both the upper and lower surfaces, the patterning follows the jagged outline of the wing's edge. It has been demonstrated that a pattern which is disposed parallel to a boundary tends to reinforce that boundary, while a pattern which ends at a sharp angle to a boundary tends to deflect attention therefrom. It will be seen that at the fore and hind edges of the wings of *Polygonia*, which are of a more normal butterfly outline, the boundaries of the different elements of the pattern are disposed more or less at right angles to the nearest edge.

In the common blenny (*Blennius pholis*, figure 1) the main elements of the pattern are disposed with their boundaries at right angles to the length of the fish. When the blenny is seen against the unnatural background of smooth sand (left lower figure) it is conspicuous enough. But when the fish is seen against the mottled background of a rock (upper figure) it will be realized that the pattern is indeed effective to conceal. The blenny is not invisible, but it is not easily or quickly seen, and as Prof. G. Hale Carpenter emphasized at the 1947 meeting of the British Association, a predator cannot afford to spend too long in search for any one prey. In both the fish and the butterfly it will be observed that the camouflage pattern is made up of strongly contrasting tones rather than of strongly contrasting colours. Tone contrasts—the contrasts between light and dark—are effective at much greater distances than colour contrasts, and it is tone contrast which is used to deflect the attention of the observer from the underlying structure. In *Polygonia* the proximal colour areas of the wings are darker just where they meet the pale distal colour patches, and in *Psammophis* the cream line is emphasized by a darker streak lying immediately alongside it. A sharp contrast of tone, such as is seen in the four

pale streaks along the back of a snipe (figure 8), produces the illusion that the pale areas are raised above the darker areas, and so masks the actual structural continuity. The abrupt termination of the pale streaks also helps to deflect attention from the structural boundaries. Patterns which tend to deflect attention from the outlines of the object which bears them are called disruptive patterns.

It is notable that in many animals the details of the pattern are scarcely visible at the ranges at which the coloration is effective for concealment. Dark and light shades merge into a single tone, just as the elements of colour, high-light, and shadow of the background mingle into a single resultant colour and shade. None the less, camouflage by use of a single merging tone is rarely or never attempted when the pattern is to be effective in a background of small diversities. Lights and darks are placed in close contiguity, and the combination of tone and colour which is perceived when they are viewed at a little distance has a luminosity which cannot be attained by a single flat shade.

Colour and tone which fit the general shade of the background are not sufficient to conceal a solid body when, as in the open air, illumination is not uniform. The appearance of solidity, which results from high-lights on surfaces upon which the illumination falls and shade on those surfaces from which light is excluded by the object's own bulk, is always sufficient to make an object stand out in relief, though in other ways it may match its background well. Countershading, the device by which the effects of top-lighting are minimized, is found in many different animal groups—in mammals, in birds, in fishes and reptiles, and in many caterpillars. The effect is to make an object which is actually cylindrical or subcylindrical in shape appear flat—and so once more to delay or prevent, not perception of the object, but its recognition. The comparatively unsubstantial appearance of the young pike (*Esox lucius*) shown in figure 2 illustrates countershading in action.

The device of countershading is an extremely simple one. The dorsal surface, on which the greatest illumination normally falls, is very dark in tone, often nearly black along the middle line. The ventral surface, on which no light normally falls, is white or silvery, and the flanks show a gradation from the dark tones of the back to the pallor of the under side. The effect of such a patterning is easy to understand. The high-lights along the back are counteracted by the dark tones

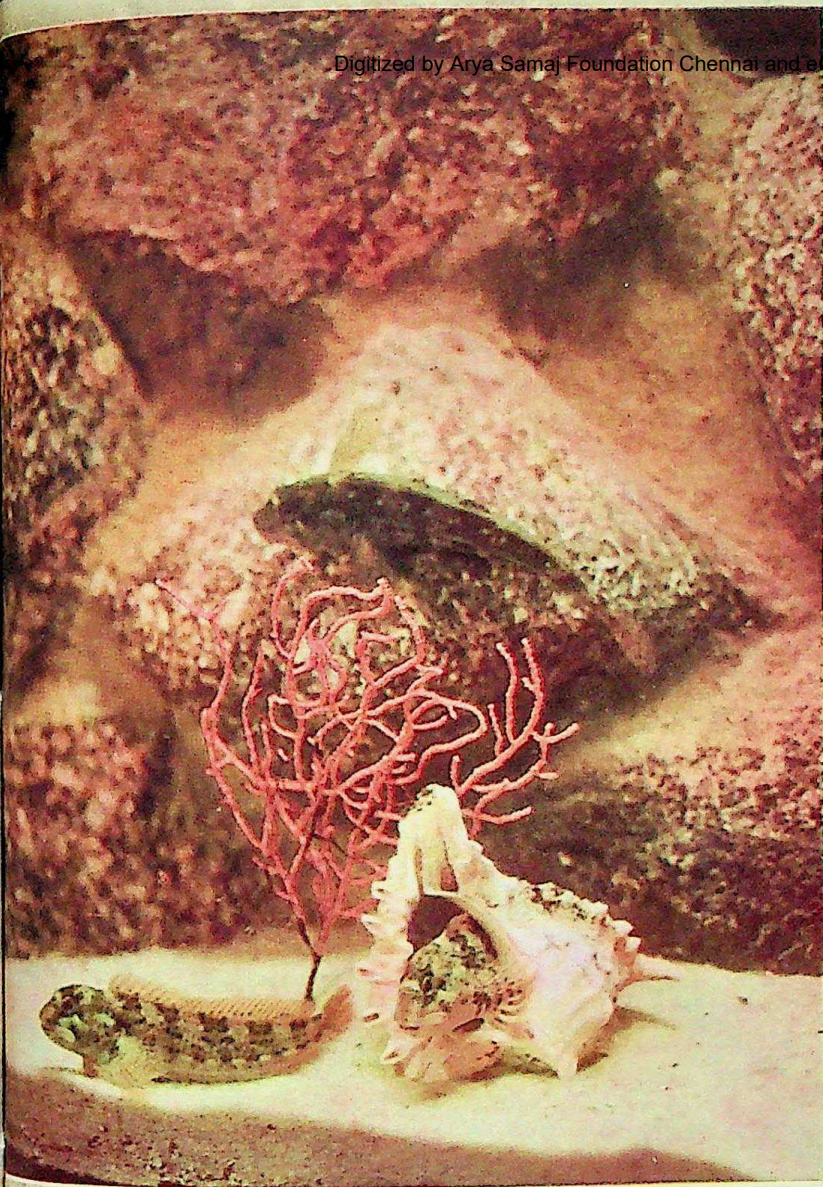


FIGURE 1 - *The common blenny (Blennius pholis)*. A group of three common blennies showing the combination of disruptive patterning and countershading.

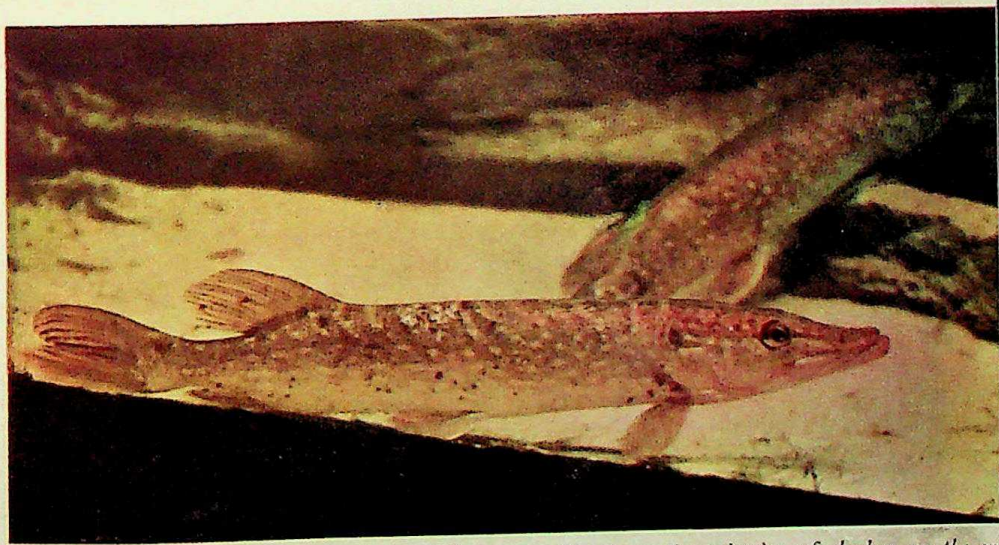


FIGURE 2 - *The pike (Esox lucius)*. The young pike shows the reduction of shadow on the surface which results from a countershading pattern.

by A. S. Samad in Chennai and eGangotri



FIGURE 3 - A leaf insect (*Phyllium pulchrifolium*). This illustrates special protective resemblance of an insect to leaves.



FIGURE 5 - The tree frog (*Hyla arborea*). Illustrating special protective resemblance of a vertebrate to leaves.

FIGURE 4 - Stick insects (Phasmidae). Illustrating special protective resemblance of insects to twigs.

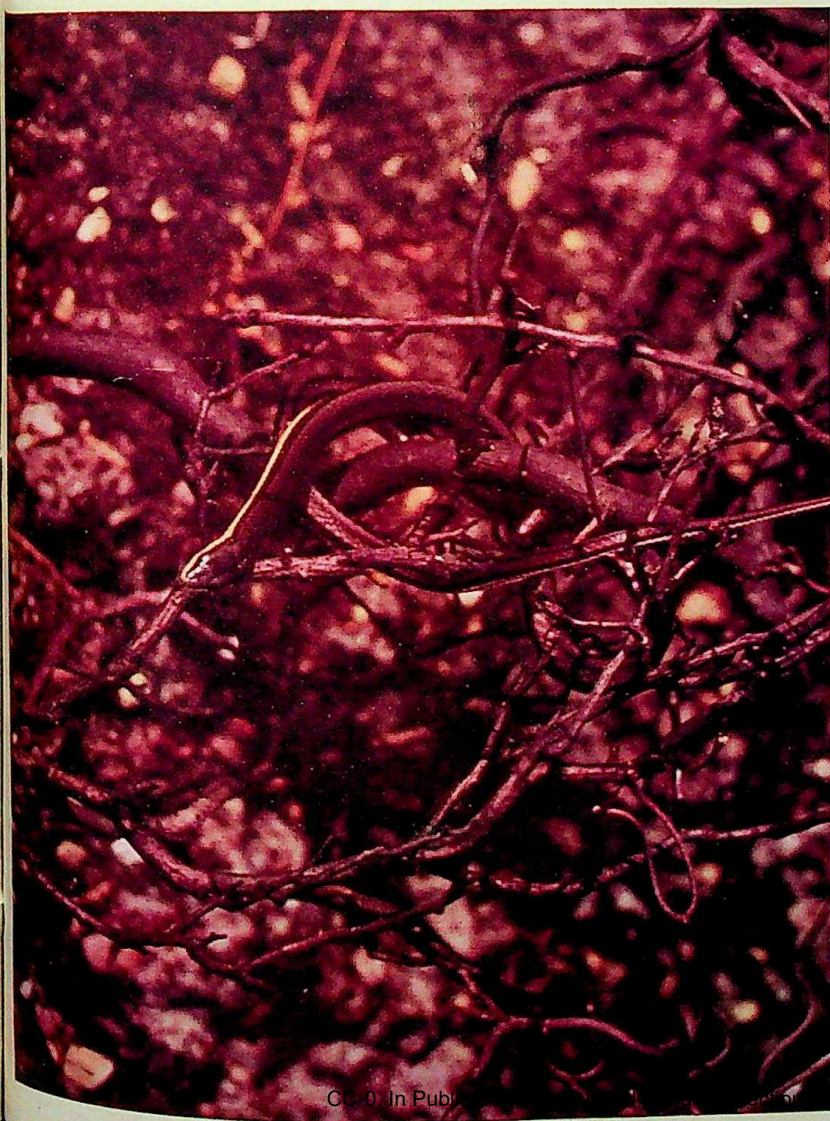


FIGURE 6 - The long line snake (*Psammophis subtaeniatus*). Illustrating the use of a patch of light colour to deflect attention from underlying structure.

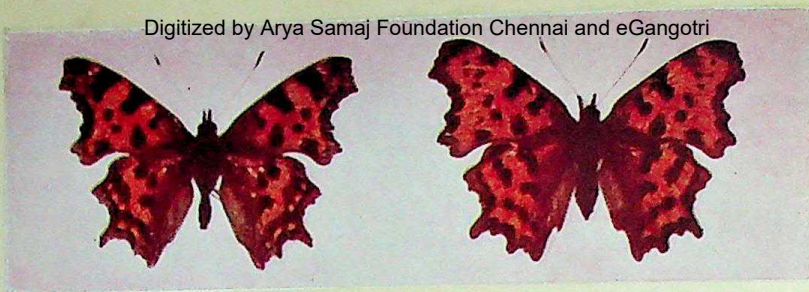


FIGURE 7 - The comma butterfly (*Polygonia c.-album*). The upper and under surfaces of the wings of the comma butterfly show the pattern following the irregular edges and at a sharp angle to the smooth edges.

(Photograph by S. Beaufoy. Reproduced from *Butterflies*, by E. B. Ford, by permission of Wm. Collins and Adprint Ltd.)



FIGURE 8 - The common snipe (*Capella gallinago*). The common snipe shows coloration adapted in the concealment in marsh country combined with the disruptive effect of pale streaks along the back.

(Reproduced from *Birds in Colour*, by Walter E. Hildreth, by permission of Wm. Collins and Adprint Ltd.)

there found. The shadow along the belly is less dense, in that it lies upon a pale surface; the graded shadows on the flanks are also made the less obvious by the tone variation of the surface on which the gradation falls. In the blenny on the sand in figure 1 the belly does not appear perceptibly darker in tone than the back, even though there is strong top-lighting. Countershading, here combined with a disruptive pattern, is sufficient to give a curved surface the appearance of being more or less in one plane.

In a few animals which habitually live belly upwards—the larvae of the eyed hawk moth, *Smerinthus ocellatus*, and one of the Nile catfishes, *Synodontis batensoda*—the coloration exhibits a countershading but the dark tones are on the belly (the illuminated surface). Stronger argument could scarcely be needed for the adaptive significance of countershading, but there is, in addition, experimental evidence of the potency of the appearance of solidity as a factor in recognition. Nice and Ter Pelwyk ('The Auk,' 38, 195-214, 1941) have shown that a cardboard outline of an owl is not a source of alarm to young song sparrows, *Melospiza melodia*, unless it be so tinted as to give an appearance of relief.

It may here be mentioned that some animals which are possessed of peculiarly powerful weapons (the skunks, for example) have a coloration which shows the very reverse of countershading, being light or white above and dark below. Such species have no need of concealment, but rather reap biological advantage from flaunting the banner *nemo me impune lacessit*. An entertaining form of animal camouflage is that which is known to zoologists as Batesian mimicry. In this form of deception, a rare and palatable animal mimics the coloration of a common and unpalatable one: the pattern of the unpalatable model is of the warning type, and makes it easy rather than difficult to see, and the mimicking species departs from the normal coloration of its group to participate in the advantages of this warning. Clearly Batesian mimics must always be much less numerous than the individuals they imitate, for there is some evidence that young animals learn to avoid unpalatable foods by trial and error, at least in part, and the gaudy warning coloration will be of no value unless most of the animals which bear it are, in fact, nauseous.

In many cases the animal which bears a pattern suitable to concealment in a particular habitat must do more than show suitable colours and tones laid on in patterns which tend to deflect

attention from its own structural outlines, and to assimilation with the background. In addition to this, the behaviour of the animal must be adapted in order fully to exploit the deceptive possibilities of its pattern. Bitterns (*Botaurus stellaris*) stretch neck and bill upward in order that the longitudinal streakings of throat and breast may repeat the vertically disposed lights and shades of the reed-beds in which they hide. Young pied shrikes (*Hemipus picatus leggei*) in the nest crouch motionless with beaks upstretched, resembling, in their mottled down, a snag upon the branch (W. W. A. Phillips, 'Ibis,' xiv, 5, 450-4, 1940).

An objection which has frequently been raised to theories of the concealing function of animal coloration is that the creature must remain motionless if its pattern is to be effective. At best this is only partly true—a brilliant yellow brimstone butterfly, *Gonopteryx rhamni*, is more obvious in a March woodland than the small tortoiseshell *Aglaia urticae*, which flies at the same time. But even if it were true that all moving animals were equally visible, the objection is still no more than frivolous, for pattern has been evolved in order that the animal may be protected in the periods when it is compelled to remain in one place.

Some of the most perfect examples of the combination of pattern and behaviour to give the greatest camouflage effect are to be found among the geometrid moths. In several species, for example *Eucosmia certata* and *Hybernia leucophaearia* (H. B. Cott, *Adaptive Coloration in Animals*, London, 1940), the wings bear a pattern in which linear elements are dominant, and these elements are so disposed that when the moth is at rest they are at right angles to the long axis of the body. In moths which are so patterned the usual resting position is with the body horizontal, a pose which brings the dominant lines of the pattern upon the wings into line with the vertical cracks and indentations of the bark of the trees on which the moths usually rest. Any other pose would place the pattern on the wings across the directional trend of the pattern of the background and make the moth a relatively conspicuous object. It has been shown by Cott (*op. cit.*) that the African hawk moth, *Xanthopan morgani*, has the pattern upon the closed wings disposed parallel to the long axis of the body; this moth habitually rests with the body vertical and not horizontal. *Xanthopan* thus brings the cryptic pattern into correct alignment with the vertical cracks in the bark of the casuarinas on which it rests. The behaviour is different from that of the geometrids, but the result is the same.

Scientific methods in the conservation of pictures

IAN RAWLINS

Some two years ago considerable publicity was given in the newspapers to the question of the cleaning of certain pictures at the National Gallery, London. A committee of inquiry was appointed which in due course issued a detailed report. The aim of the present article is somewhat different, in that its purpose is to submit a factual review of the scientific and technical methods used in the course of the inquiry. All the cleaned pictures were undamaged.

During the summer of 1947 a committee of confidential inquiry was appointed by the Board of Trustees of the National Gallery, London, to undertake 'a critical review of methods and materials used in the Gallery in procedures of cleaning the pictures...' In the course of a few weeks the committee's deliberations and findings were laid before the Board, and subsequently copies of the report (now known as the Weaver Report) became available for consultation by the public. The members of the committee were as follows: Dr J. R. H. Weaver, President of Trinity College, Oxford (chairman); Mr G. L. Stout, Head of the Department of Conservation and Research, Fogg Art Museum, University of Harvard, U.S.A. (now Director of the Worcester, Mass., Art Gallery); and Dr P. Coremans, Head of the Central Laboratory of the Belgian National Museums. Dr Weaver has already written a summary of the main contents and the conclusions reached (see *The Times*, 8th May, 1948).

It should be realized that the application of physical, chemical, and microchemical tests to paintings of supreme value and importance is of necessity limited, especially in an investigation of the kind about to be described, since no appreciable amount of experiment could be conducted upon 'models.' The masterpieces themselves were said to have suffered damage, and consequently upon them, and upon them alone, had scrutiny to be focused if really significant data were to be forthcoming. This being so, physics played a somewhat greater part in the investigation than chemistry, as might be expected from general considerations of non-destructive testing.

Ten pictures were presented to the committee for investigation, one each by Constable, Koninck, Rembrandt, and Velazquez, and six by Rubens. The treatment of seven had been the subject

of criticism in the press, and to them attention was more particularly directed. In this article we shall describe in some detail the laboratory work involved in the inquiry, selecting a few of the most crucial observations and the deductions made from them. It is not intended to produce a report subject by subject, but to demonstrate the methods employed as a whole, with characteristic illustrations from among many (about 130) to reinforce the description.

The committee has given to the world of curatorship a document of unique value, and to all lovers of art a model of objective survey in a most difficult field. The scientist will recognize techniques, seldom employed together, co-ordinated here for a common purpose.

To grasp the problem of cleaning, one must have some knowledge of picture-mechanics. This is a comparatively new subject, which sets out to study all the stresses and strains (from whatever cause) to which a painting, conceived as a system of closely associated layers, is exposed. Looked upon in this way, cleaning is seen to be but one facet—though a most important one—of the whole discipline commonly called conservation. The layer-like structure is essentially a fourfold manifold comprising (i) the support, (ii) the ground, (iii) the paint film, and (iv) the surface film. Conservation relates to all of these, whereas 'cleaning' is usually taken to denote the removal of old surface films and their replacement by a new one. The plural is used intentionally, for it is not uncommon to find the remains of several such coatings, fragments of the earliest one locked into the interstices of the design, namely the paint film itself.

Aesthetics apart, a heavily discoloured resinous film is removed because, on account of its shrinkage with time, it is a threat to the continued existence of the paint film below. The contractile forces

PLATE I - Photograph on panchromatic film of the picture the 'Woman Bathing,' by Rembrandt, before cleaning.

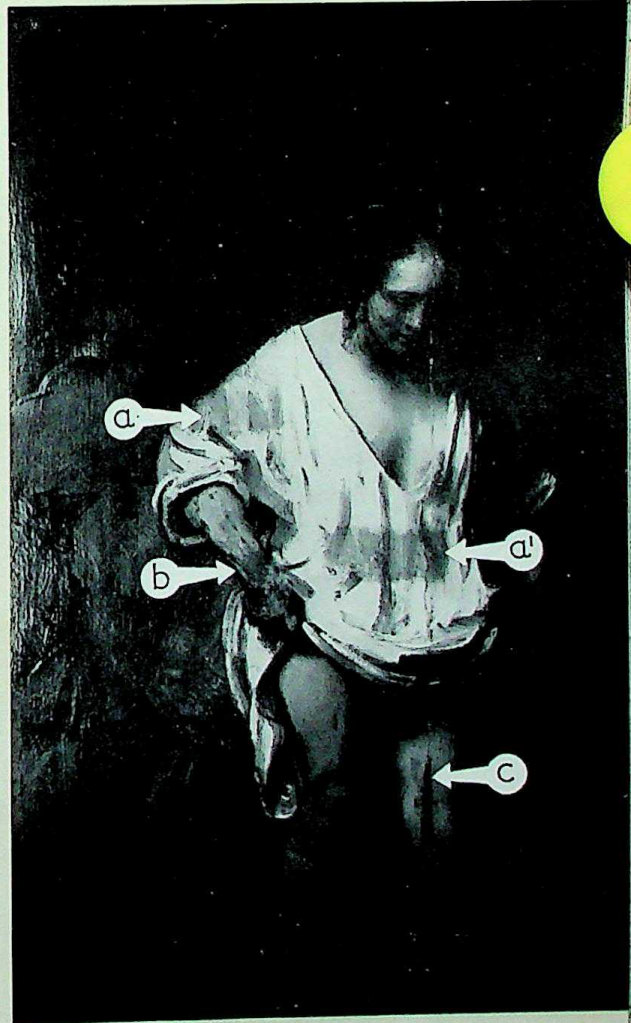


PLATE II - The 'Woman Bathing,' photographed in filled ultra-violet light during the cleaning of 1946. Previous surface coatings of darkened varnish are visible at (a) and (a'). Characteristic lack of fluorescence is displayed by overpaint at (b) and (c).

PLATE III - An X-ray photograph of the 'Woman Bathing,' taken in 1927, showing the condition of the original paint. An old crack can be seen at (a). An uneven dragging of the paint during its original application is exposed at (b).



PLATE IV - This photograph of the 'Woman Bathing,' taken early in 1947, after cleaning, illustrates the stratigraphy of the picture. Priming can be seen at (b¹), and the flow of the paint at (b²). (× 4)



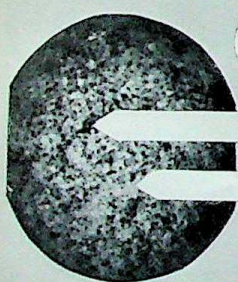
PLATE V - Photograph of 'Le Chapeau de Paille,' by Rubens, before cleaning. At (a) is a vertical split: thin paint makes the ground visible at (b).



PLATE VI - Photograph of 'Le Chapeau de Paille' by infra-red radiation. This shows evidence of an old paint layer, blue over green at (a), blue with no green beneath at (b), greenish grey on both blue and green at (c), the undermodelling of the proper left hand at (d), and of the fingers of the proper right hand and sleeve at (e).



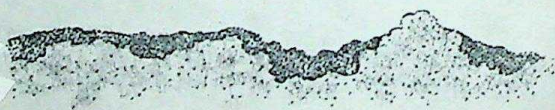
Location of
micrographs below



a

Green-grey

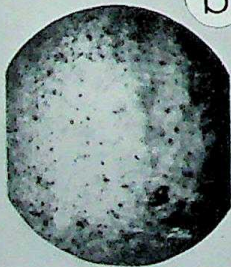
Blue



ver (green) layer
in focus

Upper (blue) layer
in focus

b



Blue

Green

Ground

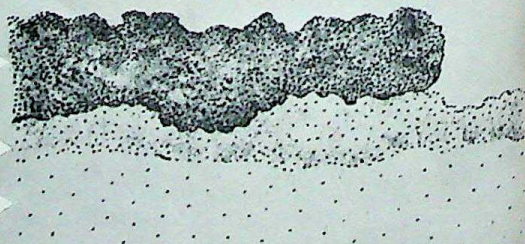


PLATE VII - This illustration shows the capacity of the microscope, using peripheral illumination, to bring out the depth relations in the paint film. ($\times 35$)

may be, and often are, sufficient to drag particles of paint away from their moorings, and if this tension is not arrested, the paint film literally falls to pieces. This is an example of picture-mechanics in a localized form, entirely different from the expansion and contraction of the support, which brings about flaking and blistering.

It will be seen at once that the suggestion that old, discoloured varnish films might be bleached is of interest; but in the present context irrelevant. Heavy surface coatings are removed not primarily because of their partial opacity and chromatic distortion, but because they endanger the stability of the strata below. To get rid of them is essential if the picture is to survive. Research might well be directed to discovering a varnish which, on ageing, did not contract (and darken), or if it did was capable of having its elasticity and resilience restored. In the language of chemical physics, this probably implies the complete reorientation of the three-dimensional girder structure which we believe these films to possess. It is not yet known whether the rigidity (a clamping down on the paint film below) occurs at the 'hinges,' or whether the intermolecular bonds tend to shorten, and so grip the paint film like a vice. At present all we can do is to dissolve away the surface film—usually with acetone—and substitute for it a preparation of mastic which will probably remain efficacious and fairly innocuous for about fifty years, when it, in its turn, should be taken off and replaced by a fresh coating. Mastic is the best protective coating yet devised, on account of its ready solubility in a solvent which is harmless to the paint below.

Michael Faraday knew that certain media in which pigment particles are embedded contain a small quantity of resin. When this occurs, great caution in cleaning is demanded, since solvent action at the surface might continue beyond the varnish-paint interface, with disastrous results. Fortunately, however, the solubility of dried oil films in organic solvents is much reduced by the presence of pigment, and thus the safety factor is greater than in industrial tests in which the action of organic solvents upon linocyn films has been fully examined when the pigment phase was absent.

Generally speaking, so far as safety allows, it is well to remove all traces of old and decayed varnish, since small remnants are not only disfiguring but may be the cause of complex swelling or imbibition, thus disrupting the paint by change of volume. The presence of resinous bodies is clearly revealed in filtered ultra-violet light at all

stages of cleaning by their characteristic milky fluorescence. This type of control has become a matter of routine in the National Gallery laboratory. It will be seen that picture-mechanics thus denotes much more than the gross shrinking and swelling to which colloidal substances like wood and other cellulosic aggregates are prone: it includes microscopical reactions taking place between particles and phases in the various picture layers.

With the main features of a painting's anatomy now fresh in mind, it is possible to explain the uses in the laboratory of the various electromagnetic radiations and to illustrate their use upon two specific examples from among the ten pictures already mentioned. These are the 'Woman Bathing' by Rembrandt (1606-69), N.G. No. 54, and 'Le Chapeau de Paille' by Rubens (1577-1640), N.G. No. 852. These two have been chosen partly on account of their importance in the national collection, but more especially because they show the power of optical methods to support our knowledge of picture structure and its modification in the course of history.

Plate I is a panchromatic photograph of the whole picture (No. 54). It was taken in May 1945, more than a year before cleaning. The paint film is a rich oil mixture; the upper layers are more lean, and upon them rich glazes are superposed. Plate II shows the picture under filtered ultra-violet light, during the cleaning in 1946. Former surface coatings of darkened varnish are visible at *a* and *a*¹. Characteristic lack of fluorescence is displayed by overpaint at *b* and *c*. An X-radiograph, taken as long ago as 1927, shows the condition of the original paint (plate III). An old crack is observed at *a*. An uneven dragging of the paint during its original application is exposed at *b*. Plate IV and figure 1, taken early in 1947, are examples of the stratigraphy or three-dimensional study of the same subject. The former, a macrograph ($\times 4$), shows the proper right hand and wrist after cleaning. Under the flesh colour is seen the priming (*b*¹). This modest degree of enlargement depicts the fluid character or flow (a rheological feature) of the original paint on the wrist (*b*²). These low-magnification images have been found of increasing value throughout, both in the present inquiry and in normal routine.

Figure 1 represents selected (idealized) sections of the phases illustrated in plate IV. Reading from the top downwards, *a* is a cut along the line of a brush-stroke, showing the elliptic edge caused by the surface tension γ of the fluid medium. The relation between γ , the depth *d*, the width *w* of a

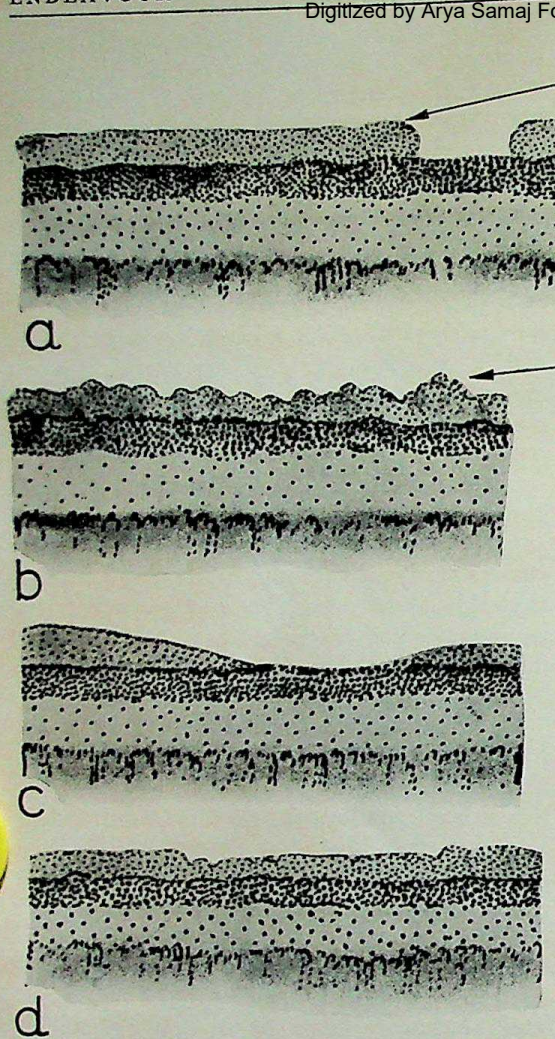


FIGURE 1 - Diagram showing selected sections of the phases illustrated in Plate IV.

brush-stroke, and the yield value f of the paint is of the form $\gamma = w^2 f / 8d$. The depth d is a measure of the levelling quality, and is sensitive to thixotropic¹ influences, but, other factors being equal, it varies inversely as the surface tension. The drying of paint is a surface effect, not a bulk one, which makes transformations very difficult to follow. To return to the diagram, a^2 is the underpaint, a^3 the ground, and a^4 the wood of the support—in this case probably oak.

Figure 1 (b) is a section across a brush-stroke, displaying the indentations made by the hairs of the brush (b^1). If attrition or erosion has occurred, the gradual slope down (c) to a 'valley' is entirely

¹ Thixotropy is the property of certain gels of liquefying when shaken and resetting on standing.

different from a. At d is seen how the brush-strokes would be smoothed off; the little ridges disappear.

In certain instances it is possible to realize all of these conditions physically, though this was not thought necessary or desirable in the present inquiry. A microscopic portion is removed from a painting, and, if circumstances are favourable and the operation is skilfully performed, a minute core is obtained, containing all the relevant strata from the ground upwards. This can be mounted and viewed under a microscope at a magnification of about 200 diameters. Alternatively, a microscopic section can be detached and prepared for mounting with a microtome.

Rubens's 'Le Chapeau de Paille' presents a somewhat different problem. The picture was cleaned in the summer of 1946. The paint is glaze-like in structure. An X-radiograph made after cleaning revealed the density in the region near the proper right hand. Here the photographic density of the (lower) glaze layer is 1.4, and of the (upper) granular paint layer 1.1, proving that the glazes have been left undisturbed.

Plate V shows the portrait before cleaning, whereas plate VI is by infra-red radiation and shows evidence of an old paint layer, blue over green at a , blue with no under-green at b , greenish grey on both blue and green at c , the under-modelling of the proper left hand at d , and the fingers of the proper right hand and sleeve at e .

The capacity of the microscope, using peripheral illumination, to bring out the depth-relations is seen in plate VII. The positions are indicated in the photograph at the top: a and b are photomicrographs at a magnification of $\times 35$; whereas on the right are diagrammatic forms of the corresponding strata. At a the green-grey layer is in focus, and the blue out of focus; at b (left) the lower green is in focus, while at b (right) the top blue is in focus. In these cases the true difference in vertical depth, after allowing for the refractive index of the medium, is of the order of 0.02 mm. These observations have led to a more profound understanding of the master's technique, and the suggestion that the original background had been removed by cleaning is untenable.

All illustrations by permission of the Trustees of the National Gallery.

The bacteriology of lakes

Digitized by Arya Samaj Foundation, Chennai and eGangotri

CHARLES B. TAYLOR

Although certain aspects of the bacteriology of fresh water have been closely investigated because of their importance in relation to public health, the fundamental principles have not received the attention they deserve. The foundations of the subject were laid by the British pioneer Percy Frankland in the latter part of the nineteenth century, but, as Dr Taylor remarks, it is only recently that interest has been revived in problems relating to the multiplication of bacteria in water, their metabolism, and their relationship to other organisms.

As long ago as 1871 Burdon Sanderson showed, by the use of flasks containing sterilized Pasteur's solution, that unfiltered water, ice-water from the purest ice, and even distilled water, contained bacteria. A few years later, following Koch's

development of a gelatine medium for the growth of bacteria and the now universal method for their enumeration, a considerable number of research workers devoted their energies to studies of the presence and growth of bacteria in water. Outstanding among these pioneers in Britain was Percy Frankland, whose classical book (1894) well demonstrates that such studies covered a wide field of both applied and fundamental research. During the past fifty years, however, increasing knowledge and appreciation of the dangers of water pollution have to a great extent limited the bacteriological investi-

gation of water to routine tests determining the degree of contamination with human or animal excreta. In the early nineteenth century the potability of water, if investigated at all, was usually assessed on the grounds of the content of organic matter. The work of Frankland and his contemporaries laid the foundations of modern sensitive bacteriological methods to detect faecal pollution, and put existing chemical tests into a secondary role. Much recent work has been directed to the development of improved or more delicate tests, and to attempts—as yet unsuccessful—to differentiate between human, mammalian, and

avian types of *Bacterium coli*, an organism which is present in large numbers in excreta and is therefore indicative of faecal contamination. Concentration of effort upon the practical problems of water pollution has resulted in a neglect of investi-

gations of the fundamental principles underlying the actual multiplication of bacteria in water, their biochemical activities, and the part they play in maintaining other forms of life in fresh waters.

Most modern systems of water-supply either include a reservoir used for storage or take advantage of a natural lake. In considering the bacteriology of water it is immaterial whether the water is contained in natural or in constructed basins, for the general conditions are similar in each. A lake is not merely a gigantic bottle of water but is an intricate system in which complex biotic, physical, and chemical

factors vary considerably. In the course of time the productivity of a lake invariably tends to increase, owing to the constant replenishment of nutrients by the inflowing rivers. Little is known in detail of the part that bacteria play in such aqueous systems, or of the biochemical changes they effect in the water before it passes to the consumer or to the sea. There are three distinct but overlapping spheres of bacterial activity in any large body of water: first, the water free from animal or plant life; second, the water containing plankton, comprising both plant and animal forms; last, the mud or other deposits at the

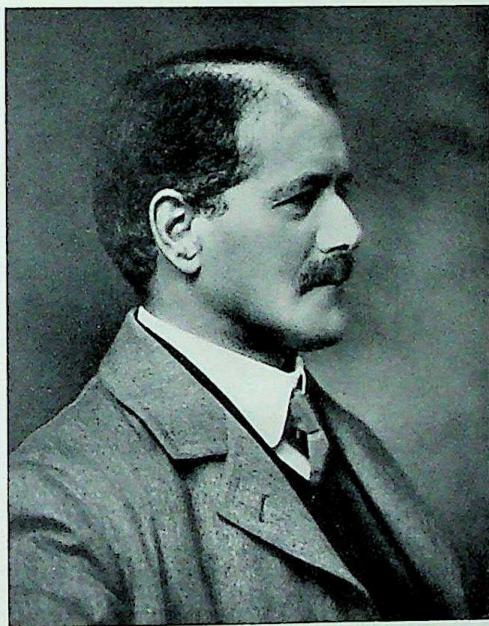


FIGURE I—Percy Frankland.

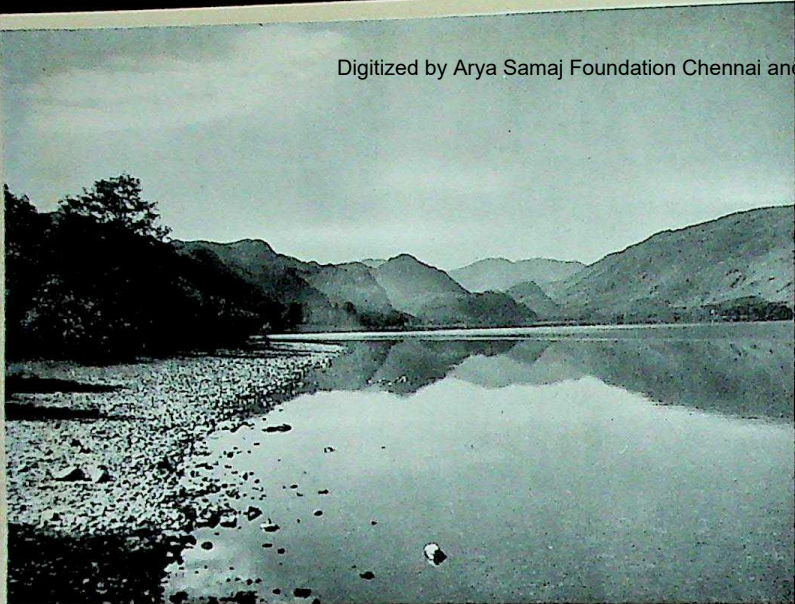


FIGURE 2 - *Derwentwater, looking towards Borrowdale. A shallow lake (maximum depth 26 metres), in surroundings typical of many of the lakes of the English Lake District.*

FIGURE 3 - *Derwentwater, looking towards Skiddaw. Reed growth, including Phragmites, in foreground.*

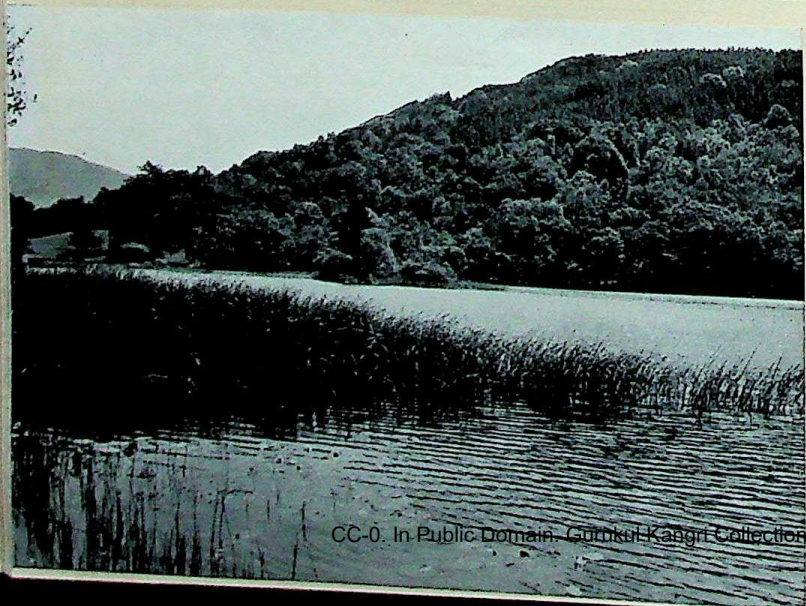


FIGURE 4 - *Rydal Water. View taken at south end near the outflow (river Rothay). This is a small, shallow lake with a maximum depth of 16 metres, flowing into Windermere. Encroachment of rushes, reeds, and water lilies shown in foreground.*

bottom of the lake. The system of water, plankton, mud is not sharply defined, owing to complex movements of the lake water set up by action of the wind and radiation from the sun.

During the winter months, unless there is an ice cover, there is normally sufficient wind to keep the water of a lake circulating freely, thus ensuring even distribution of temperature throughout the water mass, and to maintain saturation with dissolved oxygen (figure 5). Such a system allows oxidation processes to occur in the surface of the mud, and the products of decomposition are carried away to the waters above and become available again to the plankton and bacteria. During the winter, however, low temperatures inevitably restrict the intensity of bacterial activity. During early summer the temperature of the surface water of a lake rises owing to increased solar radiation, and the resulting difference in density of the water gives rise to the formation of two distinct layers of water, an upper layer or epilimnion and a lower colder layer or hypolimnion. The transitional zone between the two layers is known as the thermocline. In shallow, exposed lakes such thermal stratification may be transient, but in deep or less-exposed lakes the condition can become very stable. In the latter instance the activities of bac-

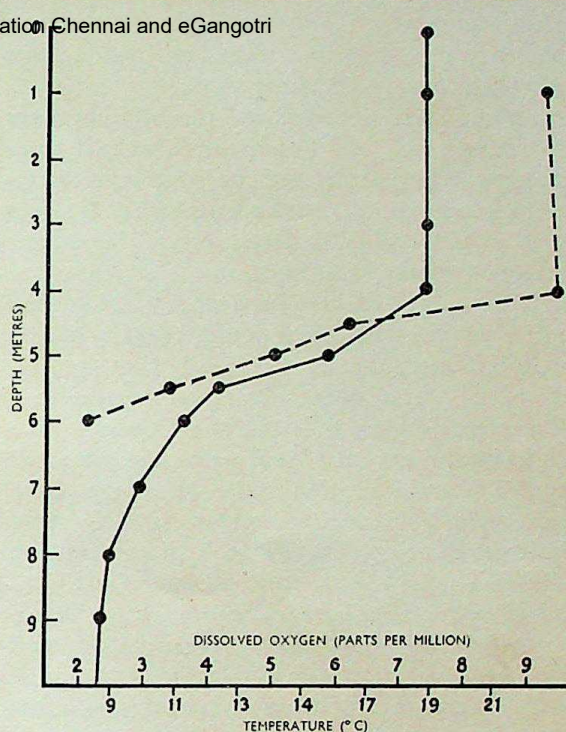


FIGURE 7 - Blelham Tarn (Lancashire). Showing temperatures (solid line) and concentrations of dissolved oxygen (broken line) at different depths during period of stratification (8th August, 1947).

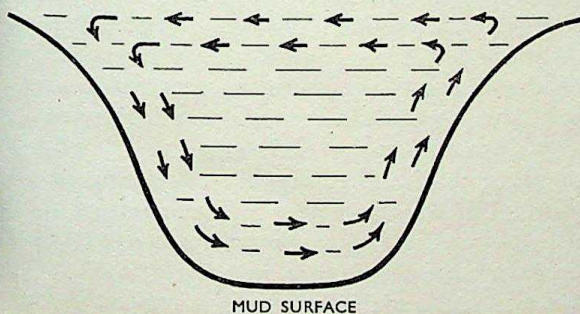


FIGURE 5 - Diagram showing circulation of water in a lake during winter.

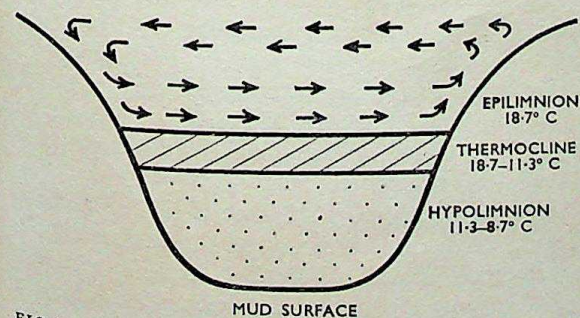


FIGURE 6 - Diagram showing stratification of the water in a lake during the summer.

teria in the mud surface, and to some extent in the water above, cause the oxygen content of the hypolimnion to become progressively less as fresh supplies from above are cut off; in the immediate vicinity of the mud surface conditions may become anaerobic. On the other hand, water movements in the epilimnion vary widely and frequently as a result of changes in such factors as wind or atmospheric temperature, the temperature of inflowing rivers (or rain), and the temperature of the lake water. Figures 6 and 7 illustrate the different conditions which develop in the epilimnion and the hypolimnion.

The concentration of dissolved chemicals in a lake is influenced primarily by the quantity washed into it and the amount consumed by the phytoplankton and, to a much lesser extent, by the bacteria. The concentration of certain substances may be so reduced by the growth of various algae that the increasing population cannot be maintained; the growth of the diatom *Asterionella*, for example, is considered to be limited by the supply of its essential nutrient silica. In any case, the concentration in solution of chemicals essential for the growth of bacteria is extremely small in most lake

waters: ammonia is rarely detected. Nitrate nitrogen rarely exceeds 1 part per million, and phosphorus 0.004 part per million.

As a lake is a receptacle for all the different types of bacteria which may be washed in by rain from the surrounding watershed or from the atmosphere, it is impossible to assess from bacterial plate-counts of water whether the types growing on the medium used are indigenous to the water or are survivors of those which have been washed in from outside sources and which would eventually find conditions unsuitable for continued existence. Results of analyses of water taken from the middle of Windermere suggest that except after heavy rainfall the bacteria present are largely indigenous and capable of multiplication in the lake water. Such types may, of course, include some which can also exist in soil or elsewhere. It is certain that rainfall is instrumental in producing greatly increased numbers of bacteria in the water. This is to some extent due to soil organisms carried into the lake, to stimulation of growth by the washing-in of nutritive substances, to increased oxygenation produced by the rain beating on the lake surface, and possibly also to the disturbance of the surface layers by the purely mechanical effect. During the stratification which occurs in the summer, bacteria in the hypolimnion diminish in numbers and are affected only by those external factors strong enough to destroy or alter the stratification. Experiments carried out in Windermere over a period of more than a year have shown that faecal bacteria washed into the lake from the polluted river Rothay, its main inflow, soon perish. Thus the average count of *B. coli* in the main inflow below the discharge from the town's sewage works was 43,000 per 100 ml; after confluence with the river Brathay at the river mouth 500 metres distant it was 15,000 per 100 ml; at a point in the lake 170 metres from the river mouth, 1,400 per 100 ml; at 400 metres, 330 per 100 ml; and at 3,500 metres, 20 per 100 ml (figure 8).

The activities of the water bacteria are not clear. They are capable of multiplying in the meagre nutritive environment which lake water affords, and, in general, their population bears a rough direct relationship to the concentration of dissolved chemicals and the productivity of the lake. Such bacteria can belong to two main, but not distinctively different, nutritional types. The autotrophic bacteria are capable of obtaining their supplies of carbon from dissolved carbon dioxide and their energy from the oxidation of inorganic substances such as nitrogen, sulphur, or iron. The

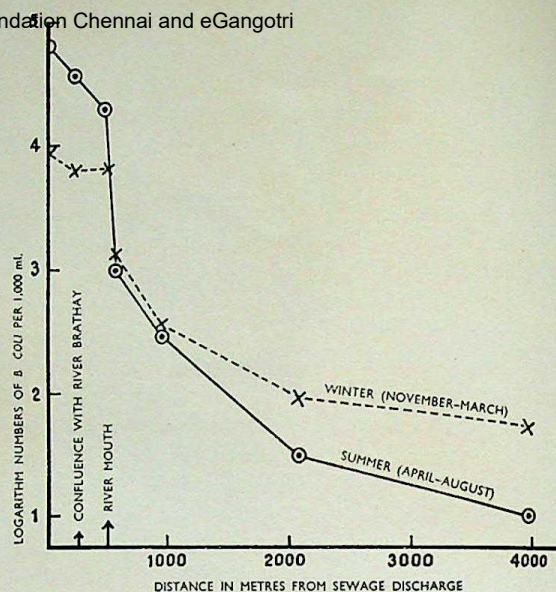


FIGURE 8 - Average weekly numbers of *Bacterium coli*, indicative of faecal pollution, found at increasing distances from the point at which sewage is discharged into the river Rothay (broken line, winter months; solid line, summer months).

heterotrophic bacteria are dependent on the carbon of preformed organic matter. Some organisms conform strictly to one type of nutrition; others are facultative. Provided that nitrogen and phosphorus are available, together with minute amounts of other essential substances, the growth of bacteria is limited by the amount and availability of the organic matter on the one hand, or the abundance of some oxidizable inorganic substance on the other. From such work as has been carried out it appears that part of the organic matter washed in from the watershed is readily available and rapidly decomposed, but the remainder is very resistant to attack by bacteria and consequently is broken down very slowly. The mere addition of appropriate inorganic substances does not necessarily initiate greatly increased growth of autotrophic bacteria, as certain other specific conditions appear to be necessary. There is, for example, constantly increasing evidence that nitrification is a surface phenomenon and hence dependent on the presence of particulate matter.

There is extremely little knowledge of the relationship between bacteria and the various planktonic animals and plants, but there is sufficient evidence to warrant certain assumptions. As the primary producers of organic matter in lake water, algae are a potential source of food for bacteria;

part of their substance, such as the silica found in the skeletons of diatoms, may be totally unavailable, but on the other hand the complex polysaccharides found in the mucoid capsules surrounding certain types of algae may be readily available for decomposition. The presence of pectic substances in some types of algae can be detected by chemical analysis or staining methods. Thus it seems likely that part of the dead algal cell may be rapidly decomposed by bacteria in the water. Processes involving the more resistant organic matter continue after the cell has settled on the bottom of the lake. There is the further possibility of a symbiotic or parasitic relationship between algae and bacteria. It has also been suggested that some algae may excrete amino-acids, and if proof of this were obtained it would seem likely that bacteria would find the vicinity of the algal cell to be particularly favourable for growth. A third possibility is that some types of bacteria which are dependent for their continued existence on a site of attachment might find temporary accommodation on dead algal cells. Experiments show clearly that there is at least a much greater population of bacteria in a concentrated sample of plankton than in the original water from which the concentrate was made. The interrelationship between the zooplankton and the bacteria in a large body of water is still not clear. Simple laboratory experiments show that many types of animals such as rotifers, which feed on particles, will ingest bacterial cells in large numbers. The effect of planktonic animals in controlling or reducing the numbers of bacteria in lake water is uncertain, but on the other hand the dead planktonic animal must prove to be a ready source of food for bacteria.

It appears probable that the surface of the lake mud is by far the most active site for microbiological activity in the water/plankton/mud complex. The numbers of bacteria in mud, as determined by plate-counts, are of the same order as those in garden soils, and it has been found that when sufficient oxygen is present in the water lying immediately above, the common biochemical processes which normally occur in soils also take place in the mud. This is not surprising in view of the fact that there is a constant deposition on the mud surface of partially decomposed planktonic cells, washed-in silt, inorganic matter, and often appreciable deposits of leaves in the early winter. It is obvious that the nature of the surrounding terrain, whether wooded, agricultural, or rocky, and the density and type of plankton in the water, directly

influence the sediments. Under aerobic conditions organic matter is broken down to ammonia and the ammonia is oxidized to nitrate. Organic compounds of sulphur are oxidized to sulphates, and inorganic phosphorus is regenerated in a form available for further assimilation. In relatively deep lakes such as Windermere aerobic conditions are always maintained, and it is assumed that the rate of the various biochemical reactions is governed by temperature, the approximate seasonal range of which is only 4–8° C. In some shallower lakes in Britain the lower layers of the hypolimnion can become exhausted of oxygen during warm weather, and the mud system becomes reduced; in exceptionally deep lakes this condition may be permanent. Such a state of affairs results in reduction of nitrates to ammonia, of sulphates to hydrogen sulphide, and of iron compounds to soluble ferrous salts. If the lake is used as a public water-supply and stratification happens to be disrupted by a violent autumnal gale, these compounds become mixed with the water in the upper layers of the lake and may result in a temporarily unpalatable water. There seems to be considerable evidence that rare and rather mysterious outbreaks of growth of certain—usually autotrophic—bacteria in lakes may be initially due to the production of reduced substances in the hypolimnion. A unique example of such a phenomenon took place in the late autumn of 1946. A large storage reservoir, which received chlorinated water of a high degree of chemical and bacterial purity and served an industrial town, turned visibly purple in colour. It was discovered that the colour was due to the presence of large numbers of an autotrophic bacterium capable of oxidizing sulphur and of producing a purple colour within the cell. A particularly mysterious aspect of the phenomenon was the origin of the relatively large amount of sulphur which must have been required to supply the energy for the development of such a vast number of bacterial cells.

Sterilization of water-supplies by the application of chemical substances is not a universal cure for the various bacterial troubles with which the industrial user of water is confronted. Typical difficulties are the blocking of mains by the growth of iron bacteria, the production of slimes, corrosion, and the development of undesirable tastes and odours. The basis of treatment lies primarily in seeking information concerning the nutrition of the responsible organisms and then preventing the establishment of conditions favourable for growth.

Some symbols used by the alchemists

Digitized by Arya Samaj Foundation, Chennai and eGangotri

DENIS I. DUVEEN

Alchemy may be studied from two points of view: as the primitive craft from which the modern science of chemistry arose, or as a system of mystical philosophy which endured for nearly 2,000 years. From both aspects, however, the important part played by symbols in alchemy is apparent, and the historian finds no lack of material upon which to exercise his skill in identification and interpretation. Mr Duveen describes some typical examples.

In the majority of their works the alchemists deliberately set out to baffle the uninitiated and to conceal their *modus operandi* from the public by the use of symbols. Thus the seven known metals were represented graphically by the astrological signs for the seven planets (including the sun and moon), and chemical operations were represented by various symbols, the true meaning of which was occasionally comparatively obvious. For example, a flock of birds flying upwards indicated sublimation or evaporation and flying downwards precipitation or condensation.

In such pictorial representation the symbolism frequently varied, but the figure of a king clad in red was used to denote gold and a queen in white to indicate silver. A yellow lion was sometimes employed to represent the yellow metallic sulphides, a red lion to symbolize the naturally occurring red sulphide of mercury (cinnabar), a green lion for salts of either copper or iron, an eagle or a crow for the black metallic sulphides, a salamander for fire, a lion with wings for mercury and one without wings for sulphur, and a green lion for 'philosophic' mercury. Solution of gold or silver by an acid was represented by a green lion devouring the sun or the moon respectively (see figure 2), and whereas antimony used in the purification of gold was depicted as a wolf, lead used in the purification of silver was usually shown as a figure of Saturn. The figure of a dragon being killed by the sun and moon represented the

combination of gold with silver. Such allegories as death, burial, and putrefaction were frequently used in describing purely chemical operations in symbolical language, and the wedding of man and woman to represent the perfection of substances.

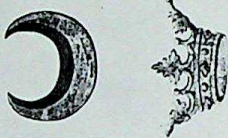
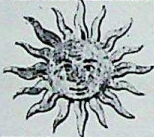
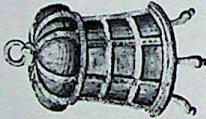
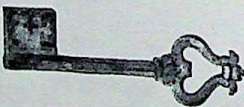
	<i>Salpeter ist der König von allen Salzen.</i>
	<i>Koper Rodt der Lies zu den alle Metallen</i>
	<i>Sal Armonacum Durch Schmelz es alles</i>
	<i>Allaun verlecht alle Metallen ins roth und ins weis.</i>
	<i>Sal Communis Schmelzt uns mit Salzen alle Dinge</i>
	<i>Queck = Silber. ist der man und das weib.</i>
	<i>Sulphur ist das weib und die Mutter.</i>

FIGURE 1 - Explanation of alchemical symbols. (From an early eighteenth-century Low German alchemical manuscript.)

CC-0. In Public Domain. Gurukul Kangri Collection Haridwar

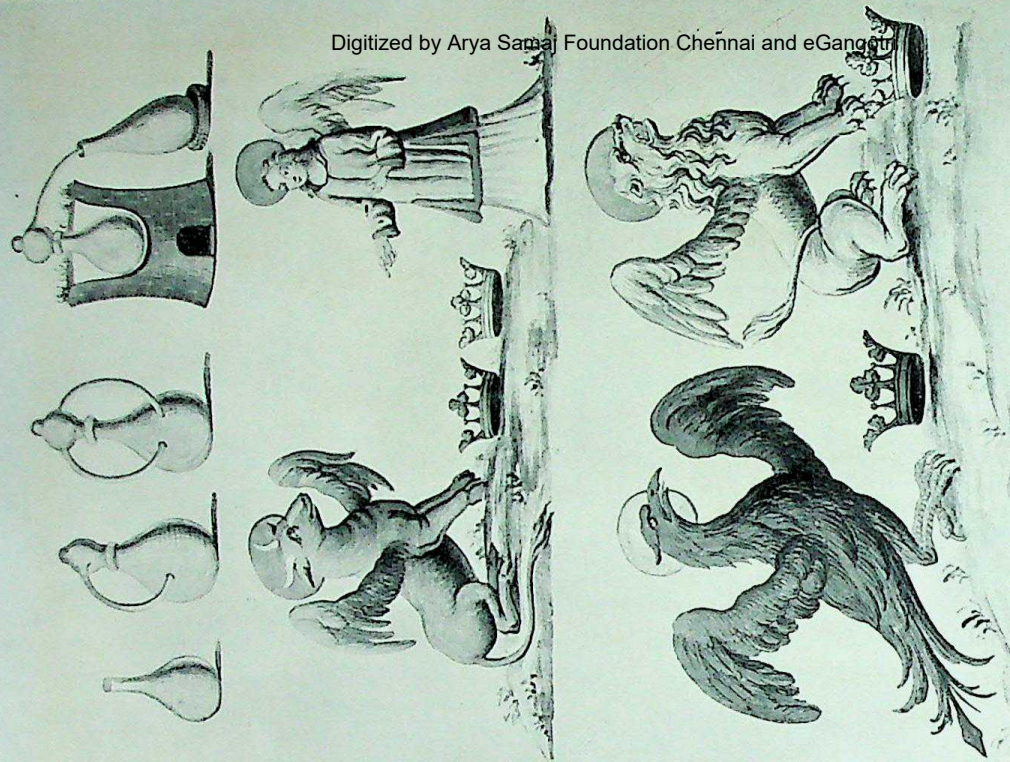


FIGURE 6 - Alchemical apparatus and symbols of the four Evangelists. (From an illuminated early seventeenth-century manuscript of the Livre de la Sainte Trinité.)

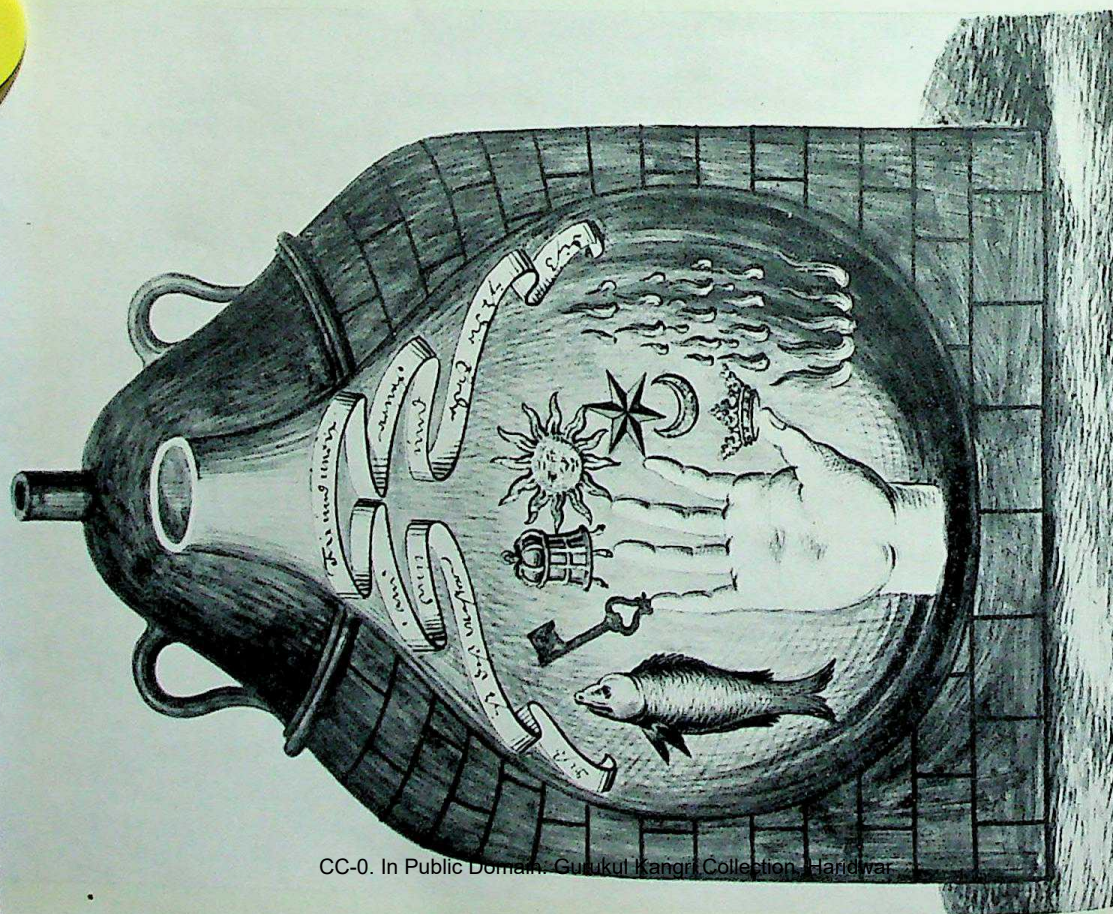


FIGURE 5 - Symbolical representation of the decoction of various ingredients to prepare the philosopher's stone. (From an early eighteenth-century Low German alchemical manuscript.)

Figure 3, which is taken from the author's copy of Mylius's *Philosophia Reformata* (Frankfurt, 1622), in which the engravings are contemporaneously hand-coloured, shows two men chatting beneath the tree of universal knowledge. The four elements (inherited from Aristotle) are here clearly shown: earth by a man and a lion, fire by a dragon (both in the left-hand bottom corner), water by a woman riding a dolphin in the sea, and air by a bird, the last two symbols being found in the right-hand bottom corner. The figures of the two men represent Senior the adept instructing Adolphus the learner and author of the book. The seven circles round the outside of the tree symbolize the stages or operations involved in accomplishing the *magnum opus* and also the colour appropriate to each stage, colours being of great importance and significance to the alchemists in their work (cf. Hopkins: *Alchemy, Child of Greek Philosophy*, New York, 1934). Reading round the tree from the left-hand bottom circle, the symbols involved are (1) a crow and skull, representing the colour black and the operation of mortification; and (2) a pair of crows, depicting distillation; (3) three crows, symbolizing sublimation; (4) two birds and a crown, representing the accomplishment of the *opus minor* and the colour white; (5) two birds and a tree, indicating the reign of Mars; (6) a unicorn and a rose bush, depicting the colour red; (7) the end of the *magnum opus* and final preparation of the philosopher's stone by a new-born infant.

The alchemists also used enigmas to conceal their secrets; as a relatively simple one may be cited that attributed to the renowned but pseudonymous Basil Valentine (see figure 4), taken from *Les Douze Clefs de Philosophie de Frère Basil Valentin* (Paris, 1649).

This pictorial enigma is a complex synthesis of alchemical thought. The planets in the firmament are shown exercising their influence upon the important combination of the masculine and feminine principles represented here, as often, by the sun and moon. The chalice, like the cornucopia, is a symbol of mercury. Referring to the symbols in the lower half of the circle, we may note the two-headed eagle representing wind or air and the lion symbolizing land or earth. The orb depicts the philosopher's stone, and the seven-pointed star refers to the seven known metals of the earth which correspond to the seven planets in the heavens.

The words *Visita interiora terrae, rectificando invenies occultum lapidem* are specially interesting, for they form an acrostic, their initial letters

spelling the words *vitriol*; this fact has been adduced to show that Basil Valentine was the discoverer of sulphuric acid!

Anagrams were also used extensively by the alchemists, although most of them are more or less impossible for the present-day student to decipher. As an example we may quote one which is to be found, accompanied by a ten-page commentary by Nicolas Barnaud, in the *Theatrum Chemicum* (vol. III, p. 744): '*Aelia Loelia Crispis* is my name. I am neither man, nor woman, nor hermaphrodite, nor virgin, nor young, nor old. I am neither a prostitute nor chaste but all these together. I am killed neither by hunger, nor by steel, nor by poison but by all these things at once. I rest neither in the sky, nor on earth, nor in the water but all over. *Lucius Agatho Priscius*, who was neither my husband, nor my lover, nor my slave, made me erect, without sorrow, without joy, without knowing for whom it was intended, this monument which is neither a pyramid nor a sepulchre but is both simultaneously. It is a grave which does not contain a corpse and a corpse which is not enclosed in a grave. The body and the sepulchre form but one entity.' Barnaud indicates in his commentary that we are dealing, in this enigma, with the philosopher's stone.

Figure 5 shows a symbol usually found associated with a treatise called *Der Hand der Philosophen*, attributed to Johannes Isaacus Hollandus. The illustration is taken from an early eighteenth-century manuscript and represents the decoction of the necessary ingredients for obtaining the philosopher's stone. In this particular instance our author has been specially considerate and has provided us with a clear diagram indicating the chemicals which each individual symbol is supposed to represent, as can be seen in figure 1, which is taken from the same manuscript. A good idea of the type of operation which Hollandus carried out can be gained from considering a translation of one of his recipes for accomplishing the *opus minor*, i.e. for preparing an elixir capable of transmuting baser metals into silver:

'Take one ounce of fine silver, dissolve it in common *aqua fortis*, then add four ounces of sublimed mercury to it in a glass pot. Set it on warm sand and let it become hot, then soak it with the *aqua fortis* in which the silver is dissolved until it has drunk up all the *aqua fortis*. Then let it cool. Pound this mercury quite fine on a hard stone. Let it dissolve of itself upon the stone, then coagulate again upon a small fire in a glass. Rub it down again as before, and dissolve as before, and so on

seven times. Of this elixir project one ounce up to thirty one ounces of prepared and well melted copper. So you will have fine silver, standing all tests.'

In addition to symbolism used to mask their proper operations, the alchemists frequently went to amazing lengths of extravagance in reading a hermetic meaning into ancient authors such as Homer and Virgil. The famous Michael Maier's most interesting work is the *Atalanta Fugiens* (Oppenheim, 1617), which is a complicated attempt to explain the fable of Atalanta and the golden apples by a hermetic analogy. The hermeticists were, however, not content with finding alchemical allegories in such fables as the wanderings of Ulysses but went farther and devised new and original ones, such as Béroalde de Verville's *L'Histoire Véritable, ou le Voyage des Princes Fortunéz* (Paris, 1610).

The very names which the alchemists gave to their tracts in many instances furnish a good indication of their flights of fancy, e.g. *The Marrow of Alchemy*, *The Triumphant Chariot of Antimony*, *The Amphitheatre of Eternal Wisdom*, *The Open Entrance to the Shut Palace of the King*.

The student of medieval alchemical literature cannot help being impressed with the frequent and apparently sincere invocations to God with which such works are usually adorned. The connection between alchemy and religion is traceable back to much earlier times, and is to be found in both Greek and Arabic alchemical writings. Connections between Christianity and alchemy went very deep, and we may cite Arnald de Villanova, the pseudo-Raimundus Lullus (it is generally agreed that the substantial body of alchemical literature attributed to Lullus was never written by the illustrious Majorcan but is the product of a later author), Petrus Bonus, and George Ripley as important alchemical authorities who made frequent use of a Christian allegory to illustrate alchemy.

The *Livre de la Sainte Trinité*, which was probably written at the time of the Council of Constance (1414-18), is a good example of the application of the allegory of the Passion, Crucifixion, and Resurrection of Christ to the realization of the *magnum opus* of alchemy. The author has dealt more fully with this particular symbolism elsewhere (*Ambix*, vol. III, No. 2), but the plate reproduced herewith (figure 6) will give a good idea of it. Beneath representations of four chemical vessels, each of which is intended for a particular operation, we find the conventional symbols

of the four evangelists. These latter figures represent at once the four elements, the four principal stages of the work, and the four cardinal virtues.

Reference has already been made to the great importance which the alchemists attached to colour. In this connection they usually divided their work into three main colour divisions, namely the black, the white, and the red. The operations leading to the production of the philosopher's stone were supposed to proceed regularly through these three colours, and the symbolism connected with them is frequently encountered. Thus lead (Saturn) symbolizes black, silver (Moon) white, and copper red. Sometimes four colours are indicated instead of three, and then the colours may be symbolized by the four seasons of the year, as in the seventh key of Basil Valentine (*Les Douze Clefs de Philosophie*, Paris, 1659). They may also be represented by four birds, the crow symbolizing black, the swan white, the peacock violet, and the phoenix red (*vide* the pentacle associated with the ninth key of Basil Valentine, *op. cit.*).

In addition to pictorial symbolism the alchemists made much use of signs to denote various materials; a few of them are reproduced in figure 7. They made the unravelling of their processes particularly difficult for the modern chemist by a lack of uniformity in so far as the exact meaning of any particular sign was concerned, and also by the extremely large number of different ciphers frequently employed to represent the same material.

When attempting any serious understanding or evaluation of the alchemists and their works it is essential to remember that they usually belonged to quite separate and distinct classes. There were the operative alchemists who were the forerunners of the chemists of today: they were interested in studying the properties of metals and other simple and compound bodies and the most suitable methods and apparatus for their manipulation. These men made and recorded numerous important scientific discoveries; they may be exemplified by Libavius, Glauber, Ulstadt, van Helmont, and Croll. In a smaller class were the speculative chemists who believed the hermetic art to be of spiritual rather than physical attainment, its meanings being veiled in allegory and illustrated by symbols. The real object of their studies was the human soul and their aim mankind's spiritual regeneration and guidance to salvation: as typical representatives of this category Khunrath, Vaughan, Fludd, and Maier may be mentioned.

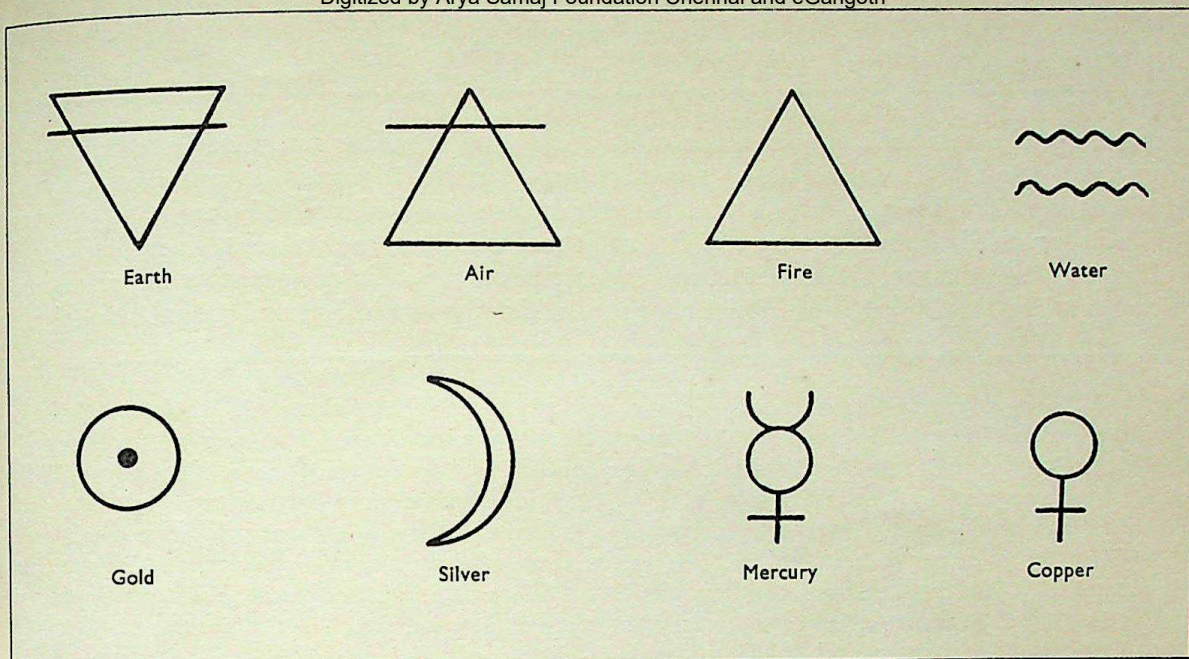


FIGURE 7 - Early alchemical symbols.

However, there was a third class which, though not very numerous, brought great discredit on alchemy: it comprised the mercenary mountebanks, puffers, and charlatans who persuaded princes and others to part with large sums of money in the hope of receiving the secret of the philosopher's stone which could transmute all baser metals into gold. Of such men Honauer, Caetano, Bragadino, and Cagliostro were among the most notorious and among those of whose final exposure we have details. As an example of the method of imitating gold and the fate which awaited the operators we may quote the tale of M. Longeville as recounted by Boyle Godfrey in his *Miscellanea vere Utilia or Miscellaneous Experiments and Observations on Various Subjects* (London, n.d. but circa 1735):

'The Process by which Longeville Imitated Gold, for which the Dutch boyled him alive in Oyl, was this—

'Take Copper four ounces, calcine it with common sulphur till it comes to an Ounce and Quarter, which must be done by several red-hot-makings and when it becomes green it is enough, then take this calcined Copper and an ounce of

Silver and half an ounce of Borax, melt them very well together, then cast it out of the Crucible, and beat off the Dross, and melt it again with as much Borax, cast it out again, and beat off the Dross as before, repeating this work a third time, then melt it again by itself in a strong Fire, adding thereto two Ounces of Gold, let it stand a while in Flux, add some Borax to it and keep it there an hour then cast it out into Ingots, repeating the fluxing till the Borax remains white, then melt this artificial Gold alone, and cast into it Grains of Nitre, till it has got a good large Skin on the top of it, then cast it into Ingots, and it is done.

'So far the Receipt as communicated to me by a German Professor of an University.

'What Faults this Man committed in his Time I know not, but I regret his Death if it was for Gold-making, for I think this process far from that; however, be it as it will, a Friend of mine knows a Gentleman who saw Longeville cast down an hollow Wooden Thing into a cauldron of boyling Oyl, when he stood so nigh it, that some of the Oyl flew on his cloaths.'

A. J. S. PIPPARD

Though the voussoir arch is one of the most ancient engineering structures, the problems of its strength and stability have proved unexpectedly enigmatic to mathematicians, physicists, and engineers. Indeed, until shortly before the outbreak of war in 1939 very little was precisely known about the behaviour of such an arch during increased load leading to final collapse. Professor Pippard describes systematic quantitative experiments, carried out by himself and some of his colleagues, which throw much new light on the subject.

The arch made of wedge-shaped blocks of stone, or voussoirs, is one of the earliest and most beautiful of engineering structures, and it would have been surprising if the attention of mathematicians and engineers had not been attracted to problems of its strength and stability. In fact, the many and varied explanations of its behaviour under load that have been advanced and the discussions to which they have given rise make an interesting chapter in the theory of structures. The earliest recorded investigations were made by mathematicians in the latter half of the seventeenth century, and as might be expected the first arguments were based on the properties of the inclined plane and wedge. It was assumed that the bearing faces of the voussoirs were highly polished and that failure of the structure occurred by slipping between some of them. In 1801 Atwood made experiments on arches with polished metal voussoirs, and the bridges designed by Rennie at the beginning of the last century were based more or less on these assumptions. A natural development was the investigation of the problem on the opposite assumption that the voussoir surfaces were infinitely rough so that slipping was prevented; failure could then occur only by the rotation of some of the voussoirs upon their edges, and this was experimentally demonstrated by Danisy. This, as will be shown later, is a first step towards the correct explanation of the mechanics of failure, but Couplet, who made the analysis, came to erroneous conclusions as to the location of the points of rupture.

Another line of approach, derived from analogy with the loaded catenary, was being developed simultaneously with this form of the wedge theory. It originated with Robert Hooke, who in 1676 included, in a *résumé* of inventions which he intended to publish later, the following passage: 'The true Mathematical and Mechanical form for all manner of Arches for Building with the true treatment

necessary to each of them. A Problem which no Architectonick Writer has ever yet attempted, much less performed. abcccddeeecefggiiiiillmmmmnnnnnooprssstttttuuuuuuuvx.' The collection of letters is an anagram announcing in concealed form a new discovery, and its solution is *Ut pendet continuum flexile sic stabit contiguum rigidum inversum*, i.e. 'As the continuous flexible (cord) hangs downward, so will the contiguous rigid (arch) stand up inverted.' This appears to be the first statement of the idea of the linear arch which has exercised such a powerful influence upon the design of this type of structure down to the present day. It was the basis of Moseley's work in this country, and French mathematicians and engineers, including Navier, Clapeyron, Lamé, and Boistard, all made important contributions to the development of the theory. Navier in 1826 showed that if the linear arch cut a joint between voussoirs at one of the points which trisected its depth the joint would be just about to open. This early enunciation of the middle-third rule, as it became known later, was apparently overlooked; it was at any rate restated as a new idea in 1840 by Méry. Much of the work of the French writers was unknown in this country for a long time, and English theoreticians and engineers were making their own attempts at explanation. Moseley in 1835 and Snell in 1846 made important contributions, the latter getting near to the correct explanation of the cause of ultimate instability in the structure by the formation of hinge points between some of the voussoirs. His treatment, however, was faulty in essential details and strictly limited in application.

Robison about the same time became interested in the failure of an actual bridge made of rather soft stone which was ascribed to overloading at the crown. About a fortnight before the collapse occurred, bad cracking of the stones was observed

at 10 ft on each side of the crown and 20 ft on one side; it was considered by the masons that final failure would take place at these points, presumably by crushing of the stone. In fact, the collapse was quite different in character; segments of the arch pivoted about the crown, at points 15 or 16 ft on each side of the centre and also about points on the abutments. Robison is said to have reproduced the same type of failure in a model made of chalk voussoirs.

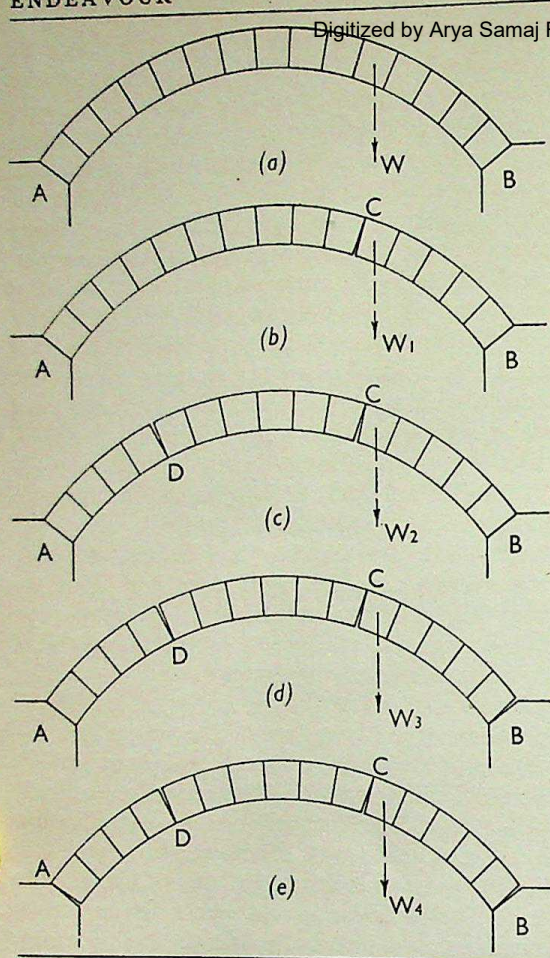
This very clear indication as to the lines upon which a solution might be found seems, however, to have been neglected; attention was again directed to the use of the inverted catenary or linear arch for design purposes. This arch received the powerful support of Rankine, who accepted as a fundamental canon of design that the linear arch must lie everywhere within the middle-third core of the structure so as to avoid the development of tension anywhere in the mortar joints. It is clear, however, that there is an infinite number of catenaries which can support a given system of loads, differing one from the other in their total length and in the value of the horizontal components of reactive forces, and so there will be an infinite number of linear arches satisfying the middle-third criterion. Considerable controversy was aroused over the selection of the correct linear arch, and it was not appreciated until much later that this was not a matter of more or less arbitrary choice but that every linear arch that could be drawn was associated with tacit assumptions as to movements of the abutments. If the abutments are to remain fixed, as would normally be hoped, only one linear arch is possible; any other requires the assumption of translational and rotational movements of one abutment relative to the other to satisfy the essential conditions of the problem.

The enunciation by Castigliano of his strain-energy theorems in 1879 provided a new approach, and in his book of that date he analysed a masonry arch by the principle of minimum strain energy, assuming in the first place that the arch was an elastic rib. When, as a result of analysis on this assumption, tension was found to occur, the portions of the arch in tension were assumed to be removed as being inoperative and a new analysis of the remaining structure was made. The process was repeated until a structure without tension resulted, from which the stresses were calculated. One objection to Castigliano's theory was the doubt as to whether a masonry arch exhibited a linear relationship between load and

deflection. This was satisfactorily settled by tests carried out on full-scale arches by the Austrian Society of Engineers in 1890 and much later by tests made by the Department of Scientific and Industrial Research in England on a number of actual road bridges. The Austrian engineers seem to have concluded in addition that, because the measured deflections were proportional to the loads applied, the arch behaved as a solid rib. This deduction is not justified by the simple evidence of proportionality, since, for example, a three-pinned structure would also exhibit such linear proportionality although the ratio between the quantities measured would be different.

The different assumptions as to the mode of failure which have been indicated in this brief survey—viz. by slipping if the voussoirs are frictionless, by pivoting if they are infinitely rough, by compressive failure of the stone, or by failure in tension of the mortar—are not mutually exclusive, and all types are possible under different conditions. The possibility of slipping is easily prevented, but, apart from that, the behaviour of a voussoir arch during the application of an increasing load until the occurrence of final collapse was still, in 1936, not properly understood, and it seemed of interest to approach the problem experimentally, since while simple qualitative experiments had been made by a few investigators no systematic quantitative tests had been attempted.

In 1936, therefore, the present writer and some of his colleagues began experiments to elucidate the behaviour of the voussoir arch. Model segmental arches were made with spans of 4 ft and rises of 1 ft 6 in, the voussoirs being carefully machined steel. One test arch had pinned ends while the other was supported on skewbacks. One end of the arch under test was fixed in position, but the other was mounted on a carriage made as free from friction as possible and restrained by a steel rod of small diameter carrying a delicate optical extensometer. The loads in this rod could thus be measured, and, the elastic stretch in the rod being taken up by a turnbuckle, the horizontal component of reaction at the free support was obtained direct. The arch was assumed to support a load of earth which filled the spandrels and formed a horizontal road surface, and this load was provided in the models by tins, appropriately weighted by shot, hung from the voussoirs. A point load of variable amount could in addition be applied to any voussoir.



on the behaviour of the arch when a gradually increasing load was applied to one voussoir, and the results which emerged can best be illustrated in diagrams.

The figure shows (a) a voussoir arch with its earth fill and in addition a load applied to a particular voussoir. As this point load is increased, the horizontal thrust at A also increases. For small values of W the thrust agrees practically exactly with the values for a solid rib of the same size and with similar abutments. At a value W_1 a change occurs in the ratio of the thrust to the applied load which is consistent with the formation of a pin at C, indicating that the arch has now effectively become two solid sections AC and BC pinned together at C, as shown at (b). If the supports are allowed to spread slightly, the 'pin' can be clearly seen to be formed by the hinging of the adjacent voussoirs at C. The new ratio of thrust to load is maintained for a time, but at a load W_2 another change occurs which is due to the formation of a second virtual pin at D (figure (c)). This pin is, however, on the intrados or underside of the arch, whereas the first one was on the extrados or outer side. The arch now consists of two solid sections AD and BC connected by a third solid section DC which is pinned to them, and it is essentially the structure of the cantilever bridge. A still further increase in the load shows that at W_3 there is another change in the ratio of thrust to load due to the formation of a third 'pin' at the intrados at B. The arch now consists of three solid sections of which one, AD, is *encastré* at A, the other two being effectively solid pin-jointed links (figure (d)). During this process there is a progressive reduction in the redundancy in the structure. The original arch, (a), has three degrees of redundancy, i.e. it may lose three reactive components and then become statically determinate: with the formation of each successive pin, one of these degrees of redundancy is lost, so that (b) has two, (c) has one, and (d) has none, i.e. (d) is a simple or statically determinate structure. If loading be continued beyond this value of W_3 , a sudden collapse of the arch occurs at a load W_4 due to the formation of a fourth pin at A which turns the assembly into a mechanism.

In the first place, a solid rib of mild steel of the same dimensions as the voussoir arch was mounted as explained above. The dead loading remained constant, and the value of the thrust or horizontal component of reaction was measured for a range of loads applied to different points. From these a curve was drawn showing the thrust due to a unit load at any point in the span of the arch. The solid rib was then removed and the voussoir arch with pinned ends erected in its place. The experiment was repeated, and it was found that until a limiting load, which varied with the point of application, was reached the results were precisely as found for the solid rib. It was established, therefore, that within certain ranges, i.e. until certain limiting loads were reached, the voussoir arch behaved in exactly the same way as a solid rib. The limiting load is easily shown to be that which produces a tensile stress in a joint adjacent to its point of application and so reduces the bearing area of the voussoirs at that section. Attention was then concentrated

These experiments clarified the mechanics of the voussoir arch and showed that while Snell's theory of failure advanced in 1850 had a sound basis it was inadequate and in certain respects faulty.

A real arch, however, is not composed of carefully machined steel voussoirs simply bearing on each other, but is normally built of dressed

masonry with joints of either lime or cement mortar. It has been accepted as a fundamental of design in masonry since Rankine's day that mortar joints ought not to be subjected to tensile stresses, and Rankine even stated that if such stresses developed in a masonry arch the structure became unstable. The experiments just quoted show that true instability does not occur until long after the first joint has cracked in tension; but the presence of a jointing material might be expected to have important effects upon behaviour, and so a second set of experiments was carried out in which the voussoirs were concrete blocks made with either granite or limestone chippings and the joints were made with either weak lime mortar or a strong cement mortar.

The arches of this series of experiments were also segmental, 10 ft in span and 2 ft 6 in. rise, and the dead load was applied in a similar way to that on the smaller steel arch. The general results of these experiments confirmed those previously obtained, but showed that even weak lime mortar was able to resist sufficient tensile stress to postpone the formation of the first virtual pin quite considerably. The cement mortar was very much more effective, and the arch made with it as a jointing material behaved as a solid rib over a much wider range of load than would be indicated by the assumption that the mortar was incapable of resisting any tension.

Interesting differences of behaviour were also apparent between the limestone and granite voussoirs. The former tended to crush and split when the virtual pins formed, but the granite gave a much stronger material and, when com-

pared with a cement mortar, gave a structure the behaviour of which agreed well with calculations made on the basis of tests on the idealized steel model.

One other set of experiments was in progress when war interrupted the work. The tests made so far had been concerned only with a single application of load to the structure, but an actual bridge is subjected to a repetitive load, and it was of some interest to determine whether this would seriously reduce the ultimate strength. The 10 ft span arches with concrete voussoirs were used for tests of this type, but instead of the point load being increased steadily until the structure failed, a fixed load was alternately applied and removed by means of a rocking lever, at a rate of about 65 cycles per minute.

When the first mortar joint cracked, a circuit was broken and the motor driving the rocking lever was automatically stopped. The number of cycles of loading applied was registered on a revolution counter.

A number of tests were made with the load applied at one particular voussoir, the magnitude of the load being varied. After one million reversals without break the load was increased and the process repeated until failure occurred. Both cement and lime mortar joints were tested, but it was possible to run only about twenty tests before interruption of the work. Enough was done, however, to indicate that although a repetitive load is more damaging than a single application, a masonry arch has a very considerable margin of strength beyond that usually ascribed to it by the conventional methods of design.

Book reviews

DETOXICATION OF ORGANIC COMPOUNDS

Detoxication Mechanisms, by R. Tecwyn Williams. Pp. 251. Chapman and Hall Limited, London. 1947. 16s. net.

The study of the fate of simple and complex organic substances in the body has attracted the interest of both the pharmacologist and the biochemist. Investigations during the second half of the last century—with which are linked the names of many famous pioneers of biochemical research such as Liebig, Hoppe-Seyler, Jaffe, Baumann, and others—have revealed the different

mechanisms by which foreign substances are metabolized. This work and its immediate continuation by Knoop, Neubauer, Dakin, and others has also brought to light many facts of fundamental importance concerning the fate of normal metabolites, such as fatty acids and amino-acids.

In more recent times many new drugs have been introduced into medicine, and, though the study of their metabolism has not led to the discovery of any fundamentally new type of detoxication mechanism, many facts of interest have emerged from it. No comprehensive textbook on the fate of

organic substances in the body has as yet been published, and therefore Dr R. T. Williams's book comes at an opportune moment and fills a gap in the literature. Dr Williams, who himself has made valuable original contributions to the field he reviews, has given a lucid and comprehensive account of the work, both classical and modern, on the metabolism of foreign substances. After a general discussion of the principal pathways of detoxication, and an interesting historical section, he has given a systematic account of a large number of organic substances of chemical or biological interest. Recent work of

topical interest, such as the metabolism of carcinogenic substances and the sulphonamides, and biological methylation, is included, and the more general implications for biochemical research are indicated. An extensive bibliography is provided, and Dr Williams's monograph should become not only a useful reference book for the specialist in the fields of toxicology, pharmacology, or biochemistry, but should also be of value to the student of chemistry or medicine.

E. CHAIN

THE ALPHABET

The Alphabet. A Key to the History of Mankind, by David Diringer. Pp. 608, with 256 figures. Hutchinson's Scientific and Technical Publications, London. 1947. 50s. net.

Far wider in scope than the title suggests, this work covers the whole field of writing—a paramount factor in civilization. Writing gives permanence to knowledge and survives, whereas speech changes.

From early signs and symbolic pictures the author traces the development of writing through various stages to the alphabet. The ideal alphabet is a distinct sign for each simple sound. We see how the alphabet follows the flag, trade, and religion, and how readily adaptable it is for reducing any spoken language to written form.

It appears that the alphabet was invented once only, but the place of origin is still undecided. Inscriptions in Sinai may be the link in development from Egyptian hieroglyphs. The Egyptians were alphabet-conscious and actually used a 24-letter alphabet. The author is not correct in stating that 'they never employed it without determinatives' (p. 63) and classes the script as non-alphabetic because many additional signs were generally used; these were helpful to the reader, since only consonants were written. He maintains that the alphabet was invented by certain Syro-Palestinian Semites.

Valuable historical notes, illustrations in profusion, and useful bibliographies contribute to the most comprehensive and detailed survey of the subject yet published. It is a fascinating story.

R. W. SLOLEY

PERMO-TRIASSIC FORMATIONS

The Permo-Triassic Formations: A World Review, by R. L. Sherlock. Pp. 367, with 15 figures. Hutchinson's Scientific and Technical Publications, London. 1948. 31s. 6d. net.

In general it is relatively easy to sub-

limited area, by reference either to the fossils contained in them or even to vertical changes in the character of the rocks themselves. But to correlate the subdivisions appropriate to one area with those of another, particularly in a different continent or other hemisphere, may, on account of lateral variation in fauna and lithology, present one of the greatest difficulties which can confront the geologist. The Continental rocks laid down under the peculiar conditions of the Permo-Trias, which contain scarcely any fossils, present all these difficulties in an acute form, and the classification and correlation of the New Red Sandstone has long been a matter of contention. It formed one of the late Dr Sherlock's main interests for thirty or forty years, and this world review is his last contribution to the controversy. In brief, he claims that the Permian System, between the Carboniferous and the Trias, has no validity, but that all rocks so designated the world over are either Upper Carboniferous or Lower Triassic in age. It is impossible to detail here the arguments for or against such a view, but it is perhaps not unfair to label this a minority report. The book is essentially one for the specialist (who cannot afford to overlook it) rather than the general reader, in anticipation of which the publishers presumably felt obliged to price the book at 31s. 6d.

O. M. B. BULMAN

DE REVOLUTIONIBUS ORBIUM COELESTIUM

Nicolaus Copernicus. De Revolutionibus: Preface and Book I. Translated by Professors J. F. Dobson and S. Brodetsky. Royal Astronomical Society: Occasional Notes, No. 10. 1947. 3s. 6d. net.

Of the classics in the history of science which remain to be translated into English, none is more outstanding than the *De Revolutionibus Orbium Coelestium* of Copernicus. There is a modern German translation, which, however, violates the meaning of the original in the very title, referring to the heavenly bodies instead of the heavenly spheres. It is therefore most fitting that the Royal Astronomical Society has resumed the issue of its valuable Occasional Notes with an annotated English translation of the Preface and Book I (together with a biographical note, portrait, and facsimile of title page) by the late Professor J. F. Dobson of Bristol

and Professor S. Brodetsky of Leeds. In view of the special interest of this publication the Society has broken its practice of issuing Occasional Notes only to its Fellows and made this number available to the general public. The translation has evidently been made with much care, and the collaboration of a classical scholar and a mathematician has ensured that it shall be trustworthy. There is a slight error in Professor Dobson's biographical note, which states that the earlier *Commentariolus* was known to Tycho Brahe 'before the publication' of *de Revolutionibus*. Since the latter was published in 1543 and Tycho was born in 1546, this would have been impossible. There is also an unfortunate slip in the diagram on page 30 of the translator's notes, by which the moon's orbit is printed as 'Mars's Orbit.' On the whole, however, the rendering is substantially accurate, and the Society is to be warmly thanked for making it generally available.

H. DINGLE

PRACTICAL ORGANIC CHEMISTRY

A Text-Book of Practical Organic Chemistry, by Arthur I. Vogel. Pp. xxiv + 1012. Longmans, Green and Company Limited, London. 1948. 42s. net.

This is an ambitious book, but it may be said at once that the ambition is fulfilled. Dr Vogel, whose previous books on qualitative and quantitative analysis are well known and appreciated, here distils for the benefit of students the experience of some twenty years of research and teaching in organic chemistry. After a brief consideration of the theory of general technique the author devotes nearly a fifth of the book to a discussion of experimental technique, including sections on chromatographic adsorption and the use of apparatus with interchangeable ground glass joints. The thoroughness of this discussion should be of the greatest possible value to both elementary and more advanced students. The main portion of the book gives careful and lucid instructions for more than 600 organic preparations, ranging from such simple substances as amyl nitrite and ethyl acetoacetate to such uncommon or complex ones as S-benzyl-isothiuronium chloride and sulphapyridine. The experimental details provided make it quite clear that Dr Vogel realizes the points at which a student may be likely to err and has anticipated them.

The value of the book is enhanced by

the inclusion of a section on quantitative organic analysis, several tables of physical constants of organic compounds, and a bibliography (with a brief guide to *Beilstein* and a full index). The volume should find a place in the laboratory of every teacher and student of the subject.

THE ELECTRON MICROSCOPE

The Electron Microscope, by V. E. Cosslett. Pp. viii + 128, with 12 plates and 39 figures. Sigma Books Limited, London. 1947. 7s. 6d. net.

This little book is intended to be an introduction to the electron microscope and its uses for the biologist and industrialist, who are not expected to have any special mathematical or physical knowledge. The book is, in fact, free from mathematics and relies on figures to make clear the physical principles involved in the construction and operation of the instrument. It can safely be recommended to any reader who wishes to have an elementary description of how this new instrument works and what kind of job it can do. Dr Cosslett also gives some indications of the present limitations and possible future developments of the technique.

The book contains seven chapters, the titles of which will serve as a guide to the contents. Starting with the eye and the (optical) microscope, the author then introduces the electron microscope and electron lenses. The magnetic and electrostatic types of instrument each receive a chapter, and mention is made of less orthodox types of microscope in which the object is scanned by an electron probe. The technique of specimen preparation, by replica and shadow-casting, occupies a chapter, and the book concludes with future possibilities.

There are a short bibliography and a useful index.

G. D. PRESTON

GERMAN ATOMIC ENERGY PROJECT

Also—*The Search for the German Atom Bomb*, by Samuel A. Goudsmit. Pp. xiv + 259. Sigma Books Limited, London. 1948. 15s. net.

Dr Goudsmit has written an entertaining account of the investigations into the German wartime activities in atomic energy which were made by the special American Alsos Mission, of which he was the chief scientist.

Reproductions or translations of German documents illustrate the astonish-

ingly inefficient way in which the German scientific effort, apart from research sponsored by the Air Force and Navy, was organised. In view of the German reputation for organization this is surprising, but Dr Goudsmit brings out clearly the reasons for this failure and draws certain conclusions of a warning nature about the possibility of the same thing happening in the U.S.A.

The book may, however, give a totally wrong impression of the state of knowledge of the Allies about the German atomic energy project prior to the investigations conducted by Dr Goudsmit in the wake of the invading armies.

The reason for this is seen at the beginning of chapter II, where Dr Goudsmit explains that he had not worked on the American atomic bomb project, and it is clear that he cannot have had access to the reports on German activities prepared during the war by the British and American Intelligence organizations. There has been plenty of published evidence, from German documents discovered since the end of the war, to show that the British Intelligence organization was both very active and remarkably accurate in many fields. It would therefore be surprising if our knowledge of one section of German wartime activity were as non-existent as Dr Goudsmit suggests. On the contrary, it is not unreasonable to assume that during the war the British and American Intelligence services produced a picture of the magnitude and nature of the German atomic energy work which Dr Goudsmit's investigations subsequently showed to have been remarkably accurate.

Dr Goudsmit seems to have considered that he was employed on an Intelligence mission. Using this word in its usual restricted sense, this is not true—the mission was a very successful C.I.O.S. Mission.

R. E. SLADE

TALK OF MANY THINGS

One Two Three . . . Infinity, by George Gamow. Illustrated by the author. Pp. xii + 340. Macmillan and Company Limited, London. 1947. 24s. net.

The intriguing title of Professor Gamow's book evokes anticipations of yet another example of lucid exposition illuminated by a characteristic whimsical humour. Nor are we disappointed. The book is something of an *olla*, and there are learning, wit, and wisdom in it, 'all working in a delicious gravy.'

What are the particular ingredients of this savoury dish? The first of the four sections into which the book is divided is entitled *Playing with Numbers* and deals in lively fashion with such topics as big numbers, prime numbers, and imaginaries. We meet friends old and new, but always attractive; the story telling how a knowledge of the properties of $\sqrt{-1}$ would have helped in the discovery of buried treasure is most fascinating.

The second section (*Space, Time and Einstein*) is an admirably clear exposition of the basic concepts of modern relativity. The third section (*Microcosmos*) sets the modern views of atomic problems against an historical background, as does the last section (*Macrocosmos*), which deals with the problem of the evolution of our universe.

That difficult but engaging fellow, the Inquiring Layman, will not find the book easy reading—the new ideas are difficult to minds nurtured in Newtonian traditions. But let him persevere to the end—he will be amply rewarded.

ALLAN FERGUSON

MAGNETIC MATERIALS

Magnetic Materials, by F. Brailsford. Pp. ix + 156, with 86 diagrams. Methuen and Company, London. 1948. 6s. net.

In this monograph the author, who is a member of the research department of Metropolitan-Vickers and who has made a number of contributions in this field, gives a comprehensive though necessarily brief outline of the present knowledge of the subject. It is suitable for advanced students, research workers, and those concerned with the applications of magnetic materials. In addition to a general list of books and summarizing articles, each chapter is provided with a very full list of references. After an introduction, succeeding chapters deal with ferromagnetism, single crystals, factors affecting magnetic properties (including cold working, vibration, and magnetostriction), silicon-iron alloys, nickel-iron alloys, and permanent magnets. In all these subjects remarkable advances have been made during the last thirty years.

At the very beginning, when discussing a permanent magnet free to rotate, the datum level of energy is taken as that when the magnet is at right angles to the field, 'the potential energy then being zero,' which it obviously is not. This introduces unnecessary minus signs and probably

accounts for the occurrence of such terms as 'it will be clear that' and 'clearly, if' four times on this single page. On page 7, $\mu_{\max} = 6,000$ appears to be a misprint for 4,000. An interesting point explained on page 6 is that the magnetic force H in oersteds is never employed; the author always uses the equivalent value of the magnetic induction B in a vacuum expressed in gauss, but refers to it as H . Although the author refers to his own work on rotational hysteresis, he apparently gives no reference whatever to either Swinburne, who first suggested the existence of the phenomenon, or F. G. Baily, who first confirmed it experimentally. The book can, however, be unreservedly recommended to anyone interested either in the theory or in the manufacture and application of magnetic materials.

G. W. O. HOWE

THE DISCOVERY OF NEPTUNE

John Couch Adams and the Discovery of Neptune, by W. M. Smart. Pp. 56, with 3 plates. Royal Astronomical Society, London. 1947. 5s. net.

The occasion of this monograph was the commemoration in 1946 of the centenary of the discovery of Neptune, and excerpts from it formed the subject-matter of two addresses given by Professor Smart at the celebration arranged by the Royal Astronomical Society. A full-length biography of Adams has never been written; but all his letters, papers, and diaries were carefully preserved and came into the possession of his close friend, Sir Donald MacAlister, on whose death they were entrusted to Dr Smart, then the first John Couch Adams Astronomer of the University of Cambridge. Professor Smart has used these private papers in the preparation of this full account of the circumstances connected with the discovery of Neptune. The broad outline of these circumstances and the violent controversies in France and England which followed the discovery are well known, but Professor Smart has given many details and extracts from letters which have not previously been published and which could not have been published while any of the protagonists were alive.

The one criticism of this monograph is that it be an historical account is a marked bias against Airy, which would possibly be corrected if Professor Smart were to read Airy's correspondence of this period. The monograph concludes with a brief account of the career of Adams subsequent to the discovery of Neptune.

H. SPENCER JONES

INFRA-RED PHOTOGRAPHY

Photography by Infra-red, by W. Clark. Pp. xvii + 472. Chapman and Hall Limited, London. Second edition. 1946. 36s. net.

Recent marked interest in the application of infra-red measurements to chemical problems has concerned mainly the wavelength range 2μ (20,000 Å) to 25μ . This region is inaccessible by direct photography, but vast improvements have been achieved in other methods of detection and measurement. Many of the new detectors can be used with advantage in the photographic range $0.7-1.2\mu$, and will now be preferred for some research problems and certain applications. For a wide variety of measurements, however, both pure and applied, photography will still be required and is more suitable. This book, by a member of the staff of the Eastman Kodak Company, provides an excellent survey of both the principles and practice, and incorporates a wealth of information on the subject. There are clear expositions of the basis of sensitization, of the salient photographic theory, and of the chemical and physical background, as well as much helpful technical guidance for the uninitiated. Typical applications are described and illustrated in many fields such as art, papyrology, criminology, medicine, botany and palaeontology, aerial survey work and camouflage, spectroscopy, and astronomy. Such aspects as sources of radiation and filters are discussed in detail. The lucid historical background adds interest for all, and the extensive up-to-date bibliography will be valuable to both specialist and general reader. Some repetition in different sections of the book does not diminish its value. The author aptly and justly refers to the

one criticism of this monograph is that it be an historical account is a marked bias against Airy, which would possibly be corrected if Professor Smart were to read Airy's correspondence of this period. The monograph concludes with a brief account of the career of Adams subsequent to the discovery of Neptune.

H. W. THOMPSON

SOLUBILITY TABLES

Solubilities of Inorganic and Metal Organic Compounds (Vol. I) and Solubilities of Organic Compounds (Vol. II), by Atherton Seidell. Pp. 1698 (Vol. I) and 926 (Vol. II). Macmillan and Company Limited, London (for D. Van Nostrand, New York). Third edition. 1947. 85s. net (Vol. I) and 75s. net (Vol. II).

The last completely revised edition of this well-known work of reference appeared in 1919, and a supplementary volume was published in 1928. Since that date a great many new data have been compiled, and the publication of this third and completely revised edition is therefore an important event. That the new edition consists of two large volumes in place of the previous single one is in itself an indication of the amount of new material which it has been necessary to include.

The arrangement of the data has been improved. In particular, a purely chemical system, based upon the chemical symbols of the elements, replaces the former arrangement based upon the English names of the compounds. This should considerably increase the value of the work to those whose knowledge of English is limited.

While the number of data listed has been increased and ease of reference has been improved, this edition is typographically inferior to previous ones. This is due to the fact that the work has grown so large that printing by ordinary methods would have rendered its price prohibitive. Offset printing from microfilm copies of original papers has therefore had to be used, with the result that the text is indistinct in places, though it is nowhere illegible. Although this defect would be intolerable in a book which had to be read continuously, it does not seriously detract from the value of a work such as this, of which only short sections are needed at any one time. This method of printing has at least one advantage which is important in a book consisting chiefly of long numerical tables, namely that the risk of errors in copying is greatly reduced.

A quarterly review designed to record the progress
of the sciences in the service of mankind

VOLUME VII

OCTOBER 1948

NUMBER 28

Scientific information

The problem of the effective publication of the results of original scientific research has become a very serious one. All over the world today there are men working along lines of ever increasing specialization who not only wish in a natural spirit of emulation—combined with the highest motives—to place their results on record promptly and in a way calculated to reach a wide circle of readers, but who need to have some method of learning promptly what other workers are achieving. The body of scientific literature, as it is sometimes politely called, is enormous. The *World List of Scientific Periodicals*, which is certainly not complete, sets down the names of 36,000 organs, and while no one scientist contemplates consulting even a hundredth of them, nevertheless the number of journals in which records of work touching one particular topic may appear is very large. The question of preparing and publishing abstracts, so as to enable the individual to learn of the existence of a particular paper, and the ensuing problem of providing him with easy access to the paper so traced, at once arise. The way in which the investigator presents his results is another grave question, for it is admitted that many records of work of significance are far from satisfactory. The whole vast subject of the recording of research was raised at the Royal Society Empire Scientific Conference held in England two years ago, and as a result of the interest aroused the Royal Society held this summer a Scientific Information Conference to consider the various aspects of scientific publication in the English language. If this restriction of language seems at first sight to limit the subject unduly it may be remarked not only that such a limitation generally increases the likelihood of obtaining that measure of agreement which is necessary if useful results are to follow, but further—a point which is not widely realized—that far

more is published in English than in any other language; in fact, it is estimated that well over half of the scientific publications of the world appear in this tongue, and there is a growing tendency today on the part of European countries to publish in English.

Those attending the Conference were drawn from the United Kingdom and the whole Empire and Commonwealth, and in addition there were delegates from the United States, including Professor D. W. Bronk, Chairman of the National Research Council and Foreign Secretary of the National Academy of Sciences. The international interest was marked by the presence of delegates from Unesco. The results reached may be taken to be truly representative of the opinion of the scientific world at large.

When a wide problem of this kind, namely the improvement of a great service which has admittedly become in many ways inadequate, is raised there are two general methods of attempting a solution. One is to destroy much of the existing fabric and to start again on fresh lines, more or less rigidly planned. The other is to attempt a gradual development and improvement, starting from the existing organization. Professor J. D. Bernal's scheme, which he submitted in a paper to the Conference and which attracted considerable attention, was to make a drastic change in the method of scientific publication. He wished to set up a small number of central bodies—'National Distributing Authorities'—to which all scientists would send papers describing their results: papers which should, it was contemplated, be in rather shorter form than at present. The Authority would send out the papers for assessment, by the same kind of experts as act under present conditions, and, on the return of the papers, would print them as separate items and circulate these 'separates' in accordance with a

predetermined plan. Another feature of the scheme was a weekly list of titles. The scientific journal as it now exists would, under this plan, be largely abolished, although certain selected papers might, it was contemplated, be issued in bound volumes periodically. The whole plan was pervaded by a genial spirit of optimism: the referees, for instance, were to return the papers within a week, but as under it everybody would certainly—speaking moderately—be not less overworked than at present, how the accelerated service was to be achieved was not very clear. Further, some doubt was left as to the exact nature of the persuasion that was to lead to the voluntary emasculation of the present publishing bodies. The scheme met with considerable opposition and was withdrawn by its author at an early stage. It is, however, well that it should have been put forward, for the debate which it caused made very clear the general conviction that the best course was to attempt reform by an improvement of existing methods: in particular by making a more extended use of the many modern methods of classification, coding, and reproduction convincingly illustrated in the excellent exhibition which was a feature of the Conference. In this conclusion the research world at large will probably agree, the wish for rigid uniformity of planning being most fervently expressed in quarters that perhaps do not represent the most original and active minds of science, although there are, of course, exceptions.

The writing of scientific papers, both from the point of view of literary presentation—a term which includes correct grammar and spelling—and from that of technical knowledge of the printer's art, was the subject of recommendations designed to make them clearer to read and cheaper and easier to reproduce. A proposal that scientists should have a better general education was not specifically made, but was implicit. Very proper emphasis was laid upon the great importance of library and information services, and proposals were made for their extension and improvement. To name one small point, the photostats so promptly and cheaply furnished by the Science Museum Library, London, are already proving

most valuable and are typical of what can be done to make the less common journals readily accessible. Increased support for this Library and that of the Patent Office was specifically advocated. The call for such reproductions of papers implies that the worker has a knowledge of their existence, and here the abstracting services are essential. Useful recommendations for improvements in this respect were among the outcome of the Conference, in particular that there should be some machinery for the prompt announcement of authors and titles of new papers. The need for increased skilled assistance to editors and editorial boards was also brought forward. What might have been emphasized was that all such matters imply a much larger body of officials of high technical competence, and it is doubtful if reservoirs from which they can be drawn exist at present, or will be found in the near future. In many matters we must simply do the best we can with the means at our disposal. On active service many excellent staff plans have to be abandoned for lack of the men and machines needed to put them into execution, and a certain amount of improvisation in all things is inevitable. The country at present is on active service. A just compromise between elaboration which cannot be realized and planless persistence along lines no longer adequate is to be sought, and the recommendations of the Conference seem to have borne this in mind.

The Conference has produced no sensations. It has, however, achieved much, and it is to be counted as a positive achievement that it has stressed the desirability of preserving and strengthening many features of the present system that are good and working well. The very fact that it has brought the whole complicated question of scientific publication prominently before the working scientist is a valuable service. The problems concern him closely, and he should think about them as he thinks about his laboratory problems; that is, as soluble enigmas and not as features of the landscape. The matter has been brought into the open, and the Council of the Royal Society has agreed to appoint a Standing Committee to deal with the scientific information services.

Editor: E. J. HOLMYARD, M.A., M.Sc., D.Litt., F.R.I.C.

Deputy Editor: TREVOR I. WILLIAMS, B.A., B.Sc., D.Phil.

Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1

Modern colour photography

C. E. KENNETH MEES

Although the principles of photography in colour have been known for nearly a century, it is barely forty years since the first colour plates were put on the market. Since that time great progress has been made. Transparencies which faithfully reproduce the colours of the original had been brought to a high standard even before the war, and now, partly as a result of the military need for easily processed colour photographs, the printing of coloured photographs direct on to paper has become practicable even for the amateur photographer.

The history of colour photography begins with a lecture that Clerk Maxwell gave in 1861 at the Royal Institution in London on his theory of colour vision. He there demonstrated the fact that all colours may be matched by mixing, in various proportions, light of the three primary colours—a pure red, a pure green, and a blue-violet. To illustrate this, Maxwell had taken three photographs—one through a red solution, one through a green solution, and the third through a blue solution. From these three negatives three positives were made in the form of lantern slides, which he projected on to a screen on top of one another by means of three lanterns, each one projecting its slide through the solution that had originally been used for taking the negative. In this way a coloured picture was obtained on the screen.

When three lanterns are used to project the three primary colours upon a screen, they can be adjusted in intensity to produce white, and any required colour can be produced by a proper adjustment of the intensities of the separate beams. Thus, as we see from figure 1, the admixture of the red and green beams of light produces yellow, the admixture of the green and blue-violet produces a blue-green, and all three colours together produce white.

The additive method of colour photography—making three negatives through three colour filters, obtaining from them three positives, and then projecting these positives through filters similar to those through which the negatives were exposed—has been utilized by many workers since the time of Maxwell. The greatest objection to this process is that the pictures can be seen only when projected from a rather elaborate lantern. Most people, however, want pictures either to put on the walls of their rooms as prints, or at least in such a form that they can hold them in their hands and examine them. The efforts of

inventors in colour photography have therefore been directed toward getting some form of colour photograph that could be viewed apart from a projection lantern.

In 1869 a very wonderful little book called *Les Couleurs en Photographie* was written by a Frenchman, Louis Ducos du Hauron, and in this book du Hauron outlined many of the possible processes of colour photography that have since then been brought into practice. One of these processes which has since become of importance is known as the 'screen plate' process. Du Hauron suggested that the surface of a support might be covered with tiny filters and that a colour-sensitive emulsion could be coated on top of the filters. Such a material can be used to take a direct colour photograph in which the image is cut up into a lot of little sections, each of which is taken through one of the three filters.

The earliest successful colour screen unit process was that invented about 1904 by the Lumière Company in France, who coated the surface of a glass plate with dyed starch grains derived from rice. The little spherical grains of starch were dyed red, green, and blue and then mixed thoroughly, scattered over the surface of the plate, and squashed into flat disks. The interstices were filled with carbon black, the coating was varnished, and then the emulsion was coated on the face of it. A photomicrograph of the screen is shown in figure 2. These plates were put on the market forty years ago under the name of *Autochrome* plates, and with them many beautiful colour photographs have been made.

In the screen plate processes of colour photography, as in the method of triple projection, the colours are formed by the admixture of coloured light of the three primary hues. In nature, however, objects appear coloured because they absorb some of the components of white light. In figure 3 we see the three primary colours—red, green, and

blue-violet—and just under them are printed patches of the colours which are obtained when each of the primary colours in turn is absorbed from white light and which are therefore said to be complementary to them. Thus we have blue-green, cyan, or *minus red*, which is complementary to red; blue-red, or magenta, *minus green*, which is complementary to green; red-green, seen as a yellow, *minus blue*, which is complementary to blue-violet.

If in one of the beams of a triple lantern, say red, we put a positive made from the red filter negative, on the screen we shall get a cyan image of the positive formed by the blue and green light, the red being absorbed by the positive (figure 5). Clearly we can obtain exactly the same result if, instead of making a black positive from the red negative and projecting it in the triple lantern, we print the red negative in a cyan dye. Similarly, we can duplicate the projection of the positive from the green negative by printing it in a magenta dye, and that of the positive from the blue negative by printing it in a yellow dye, and when these three prints are superimposed they will give exactly the same result as the triple lantern: a picture in natural colours. Thus figure 4 shows at the top three negatives taken through three colour filters—red, green, and blue-violet. Below them we see three positives, and if these were projected on to a screen by means of red, green, and blue-violet light respectively, we should get an additive colour picture.

Instead of doing this, we can print the red negative in cyan ink, the green negative in magenta ink, and the blue-violet negative in yellow ink, and when these are superimposed we get a subtractive colour picture (figure 6).

Thus there are two distinct methods of making colour pictures from the triple negatives: the additive method (in which the three colours are added in projection) and the subtractive method (in which the colours are produced by the superposition of prints). The subtractive processes of colour photography are those used for the preparation of colour pictures for use in illustrations, e.g. for commercial and advertising photographs.

In order to get a subtractive colour photograph it is necessary to make three negatives, exposed respectively by means of red, green, and blue light, and then to make from these three negatives three dye images so that they can be superimposed. A very simple method of colour photography would include a material in which the light-sensitive layers with the necessary filters

were incorporated in one material on top of each other, provided there was some way in which dye images could be formed after the exposure and development of the layers. This was proposed by Karl Schinzel in 1905, and Schinzel's proposal seems to be the first explicit disclosure of a monopack, as such films are now called.

Schinzel proposed that the colour images should be obtained by putting the necessary dyes into the three layers and then using the silver images to reduce the dyes catalytically. Other processes were suggested by which the dyes could be produced in the three layers. For instance, Homolka discovered that a number of developing agents, when they develop silver and are themselves oxidized, could form dyes by the combination of the oxidized developer and other chemicals, which are now known as couplers. In this way dye images could be produced in development, the silver being removed subsequently by a bleaching process.

The use of this dye-coupling process for producing a colour picture was patented by Rudolph Fischer in 1912. He proposed a monopack with the three colour-sensitive layers coated on the top of each other. In each layer he proposed to put a coupler which would form the suitable dye—a cyan-producing coupler in the bottom layer, which is sensitive to red; a magenta-producing coupler in the middle layer sensitive to green; and a yellow-producing coupler in the top layer sensitive to blue (figure 10). The chief difficulty with this process when it was tried was that the chemicals employed did not stay in their own layers. For instance, Fischer's couplers wandered to the next layer from the layer in which they should be, and thus satisfactory discrimination between the layers was not obtained and no good colour images were produced. Even worse than the wandering of the couplers is the wandering of the sensitizers. The three layers have to be sensitive to the three regions of the spectrum. This is accomplished by the addition of sensitizing dyes to the emulsion. An ordinary photographic emulsion is sensitive to blue and violet light. When it is treated with various magenta-coloured dyes which absorb green light, it becomes sensitive to green as well as blue and violet. When, however, it is treated with some blue dyes which absorb red light, it becomes sensitive to red as well as blue and violet. In a monopack, the top layer is not sensitized and is sensitive to blue and violet and also to green, and the bottom layer is sensitive to blue and violet and also to red. Between the top

Digitized by

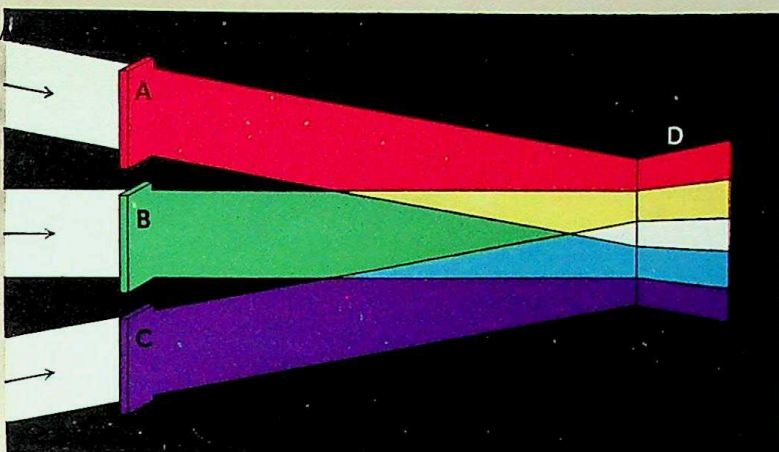


FIGURE 1 - Additive synthesis of the three colour primaries.

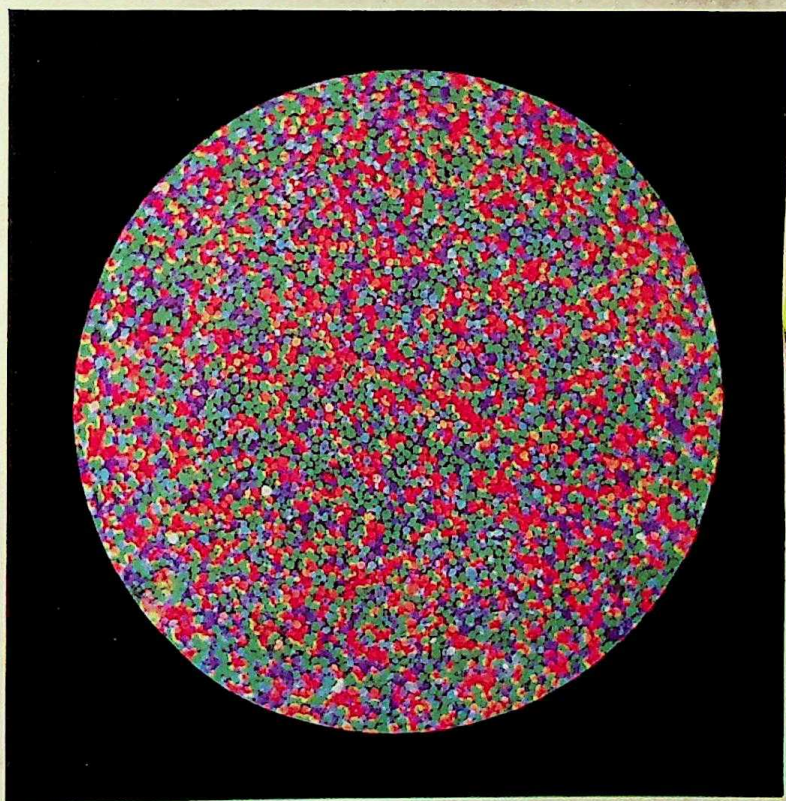


FIGURE 2 - Photomicrograph of the Autochrome screen.

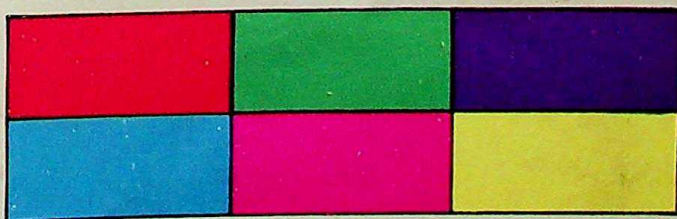


FIGURE 3 - Primary and complementary colours.



FIGURE 4 - Colour-separation negatives and positives.

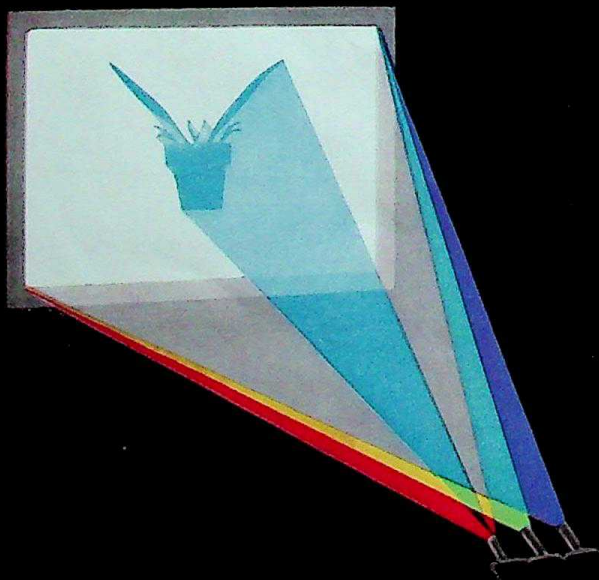


FIGURE 5 - Three-lantern projection of cyan image produced by a positive in the red beam.
on, Haridwar



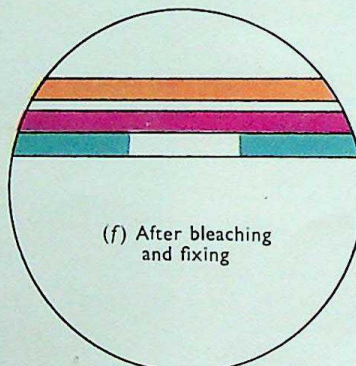
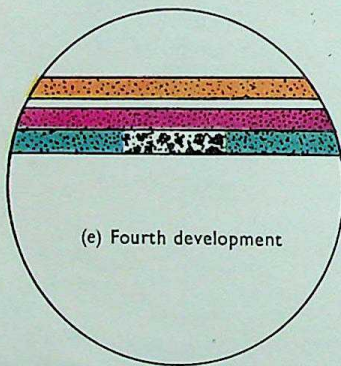
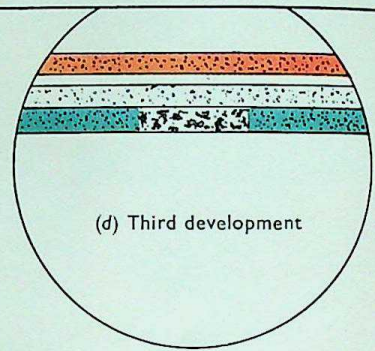
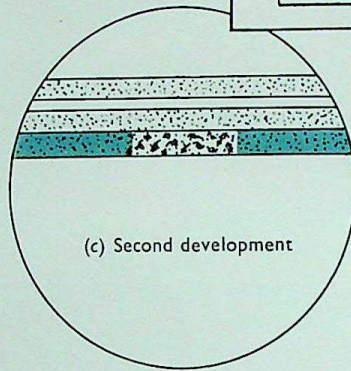
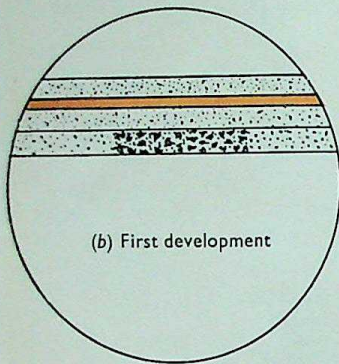
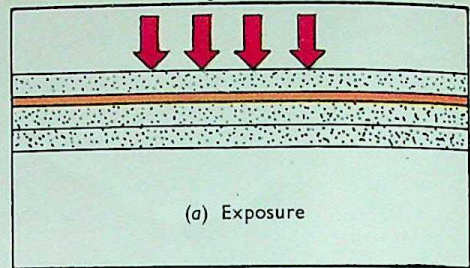
FIGURE 6 - *Reproduction by the three-colour subtractive process.*



FIGURE 7 - *Kodachrome negative and print.*

PROCESSING KODACHROME FILM

Explaining the sequence of operations in processing Kodachrome, a cross-section of the film is shown at the completion of each main stage in processing. In the case illustrated the film was exposed in the camera to a red object on a black ground.



ON PROJECTION, the red colour is obtained by reason of the 'window' in the blue-green layer. Any other colour may be obtained in analogous fashion by a different combination of wholly or partially clear 'windows' in the three layers.

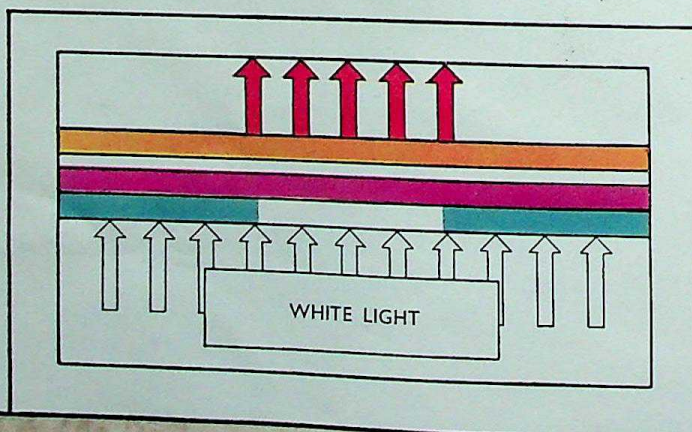


FIGURE 8 - Processing Kodachrome film.

layer and the middle layer there must be coated a layer of yellow filter, a dye being chosen which can be destroyed during processing but which during exposure will prevent blue and violet light from penetrating the lower layers, so that the top layer is exposed by blue light, the middle by green light, and the bottom by red light.

The sensitizing dyes must stay in their proper layers, but the earlier sensitizing dyes did not easily do so. They wandered into other layers and so prevented the separation of colours from being achieved in a monopack. About 1930, however, great numbers of new sensitizing dyes were discovered, and from these it became possible to select those that did not easily wander through the gelatin but would remain attached to the silver bromide and would retain that position during the coating of the emulsion.

At that time two young American musicians, Leopold Mannes and Leo Godowsky, had become interested in chemistry, especially that of colour photography, and had worked together for a number of years. When it was realized that sensitizing dyes could be obtained that did not wander, Mannes and Godowsky were invited to join the Kodak Research Laboratories in Rochester, New York, and there they worked out the first effective monopack process, the one called *Kodachrome*, which was placed on the market in 1935.

The Kodachrome film is coated with the three light-sensitive emulsions in the usual order—the red-sensitive next to the base at the bottom of the emulsion, the green-sensitive above it, then a layer containing a yellow filter material that prevents the blue light reaching the green- and red-sensitive layers, and then on top the unsensitized emulsion to record the blue and violet light. The layers do not contain any material intended to produce dyes; these are introduced in the processing operation. It was originally necessary to process the film three times, introducing the dyes in turn in the three operations, but this complicated processing was eventually simplified so that the film is processed in one continuous operation. As this procedure is carried out at the present time, the Kodachrome film after exposure is first developed with an ordinary black and white developer, which develops the silver negative in the three layers. Then after simple washing it is exposed through the back to red light, which makes developable in the bottom layer the silver bromide which was not exposed, and which, therefore, was not developed in the first development.

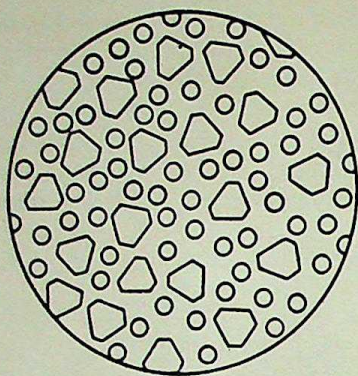
Now the film passes into a developer containing both a colour developer and a coupler, which will produce a cyan positive in the bottom layer, because the image now developed in cyan is made from the silver bromide not exposed originally and so not developed in the first developer. It is reversed compared with the original negative exposed in the bottom layer. The film is next exposed to blue light from the top, and a yellow positive is developed in the top layer. Finally, the unexposed silver bromide in the middle layer is developed with a coupler-forming magenta dye, and then the whole of the silver that has been developed is removed by a bleaching bath (figure 8).

The Kodachrome process was quickly adopted for the 16-mm and 8-mm film used for amateur cinematography. The cost of the film was not greatly in excess of that of the black and white film, and it was only a short time before most of the film used for home 'movies' was colour film.

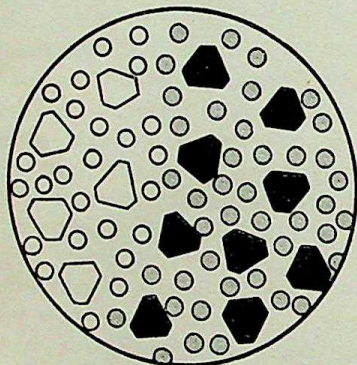
Another development that followed was the introduction of 35-mm film of the same kind for making still pictures in the well-known miniature cameras that have been so popular of recent years. The pictures are, of course, transparencies, but in order to make them useful a system was introduced of mounting them in card mounts at the time they are processed, and supplying simple and cheap projectors with which they can be projected on a screen. This process has been a very great success, and tens of millions of these little pictures are now made every year, with results that gratify those who take them.

While this Kodachrome process had been worked out in the United States, the German Agfa Company had been working on the Fischer process invented in 1912. When non-wandering sensitizing dyes could be obtained, they could study the remaining difficulty of the Fischer process—the wandering of the couplers. Organic chemists worked out a number of dye couplers having molecules of large size, which would pass through gelatin only with great difficulty. Thus a process was evolved in which the couplers were each in its own layer and were not required in the developers, as was necessary in the Kodachrome process. Film made by this process has been placed on the American market by the Ansco Company, formerly associated with the German Agfa Company.

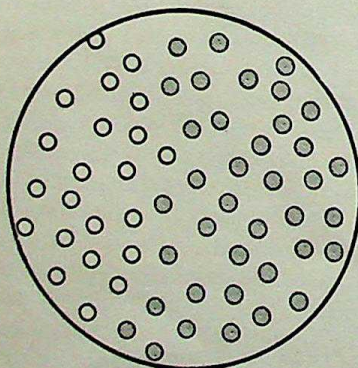
In 1940 the U.S. Army decided that they must have some method of taking colour pictures which they could process in the field. Although the Kodachrome process can be operated easily



Emulsion showing crystals of silver bromide and globules of coupler dispersed in gelatin.



Magenta layer of emulsion after development, showing dye image and silver image.



Magenta layer of emulsion after removal of silver and silver bromide.

FIGURE 9 - Kodacolor emulsion, showing the formation of dye.

on a large scale with continuous machines, it would be very difficult indeed to operate in the field.

In order to obtain a film that could be processed in the field, it was necessary to incorporate the couplers in the layers. To ensure freedom from wandering, the couplers are dissolved in organic solvents, which are then dispersed in the emulsions as very small oily globules, much as the butter fat is dispersed in milk. When the film is developed, the oxidized developer diffuses into the globules and there reacts with the couplers to form dyes (figure 9).

In the new film three types of coupler are dispersed dissolved in the globules, one in each emulsion layer, so that after development the bottom layer (which is red-sensitive) gives a cyan image, the middle (green-sensitive) layer a magenta image, and the top (blue-sensitive) layer a yellow image. If the film, therefore, is developed after exposure with a colour-forming developer, the oxidized form of which can unite with the couplers to form dyes, the three layers will be developed, and after removal of the silver by a bleaching bath a colour negative will be obtained in which not only are the tones reversed, so that black is represented as white and white as black, but the colours are reversed and are shown as complementaries. Such a negative is shown in figure 7. When this negative is printed on a paper or film of the same type, a colour print is obtained, as is shown in the figure. This process is called the *Kodacolor* process, and in addition to its military use for taking aerial photographs it was put on the market in the form of roll film suitable for the ordinary roll film cameras. After exposure, the film is processed to give negatives and then printed on a special paper to make colour prints. Many millions of these colour prints are now being made each year.

Both the Kodachrome film—in which the couplers are introduced during development—and this Kodacolor film are available in the form of cut sheets for use by professional and commercial photographers. The Kodachrome Cut Sheet process, which was introduced in 1938, gives transparencies, since the film is developed by reversal. It has one serious disadvantage from the standpoint of a commercial photographer. The film has to be sent to a processing station and the photographer must wait until the pictures are finished. To make it possible for the photographer to develop his own film, a film of the Kodacolor type intended, however, to be

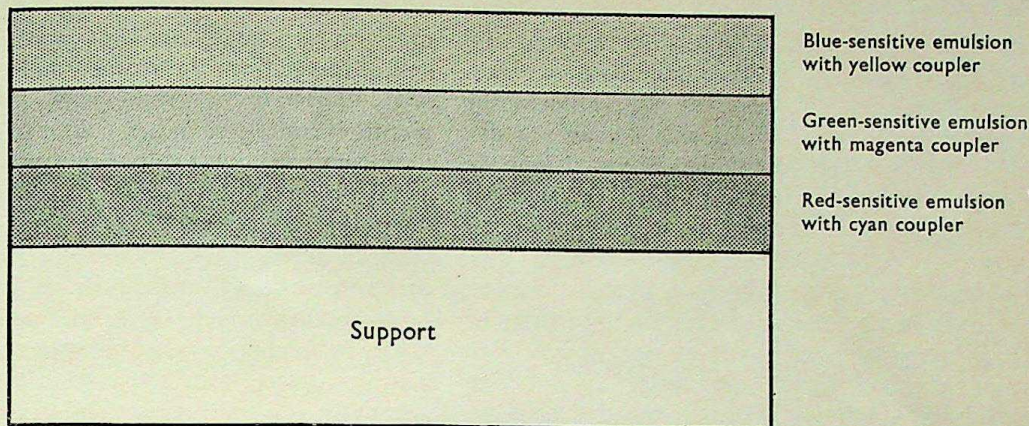


FIGURE 10 - Tripack proposed by Fischer.

developed by reversal to a positive, has been put on the market under the name of *Ektachrome*. This film contains the familiar three layers, each containing the appropriate coupler dispersed in the microscopic globules. The film is developed first with a black and white developer to get a negative, and this is then exposed to white light and redeveloped with a colour developer.

Cut sheet colour transparencies can be used to make colour prints. To do this, separation negatives must be made from the transparencies. Colour transparencies suitable for viewing, however, generally have a scale too long to permit of the making of satisfactory prints. This difficulty can be controlled by the use of a mask. If from the transparency we print a negative on a sheet of film, develop it to a low contrast, and register it with the transparency, the over-all scale of the transparency will be lowered in proportion to the scale of the negative. At the same time this mask tends to overcome another difficulty that arises in making duplicates or prints from colour transparencies which is even more serious than the difficulty introduced by the extended scale of the transparencies: it is that the spectral characteristics of the dyes are not perfect, and that when the error of these dyes is repeated in a duplicate, the colour rendering is visibly unsatisfactory. A perfect cyan dye should absorb red light only, but in practice the best cyan dyes obtainable absorb a considerable amount of green and blue light. The magenta dye, which absorbs the green, is free from absorption of the red light, but it absorbs blue to a very considerable extent. The yellow dye is, on the whole, satisfactory, its absorption for the green and red regions of the spectrum being small. As a result of this absorp-

tion of green by the cyan dye and of blue by both the cyan and magenta dyes, a duplicate or print from the colour transparency will show excessive brightness of the reds and yellows compared with blues and greens, which are degraded by the unwanted absorptions. Some correction can be obtained by printing by red light the negative mask registered with the transparency. Although the correction obtained in this way is not perfect, it does much to mitigate the excessive brightness of the reds and yellows in the print.

In Kodacolor film, used to obtain complementary negatives in roll film cameras, a masking emulsion is coated on the original film. After the development of the colour negative, the mask is exposed through the negative to red light and is then processed as the last stage in the processing of the film, so that an integral mask is obtained when the roll film is processed. This method of obtaining a mask is quite satisfactory for roll film, but the making of masks in register with transparencies, while quite feasible, is not very easy.

A superior method of overcoming the masking difficulty for negatives has recently been worked out. Couplers are used which are not colourless but which themselves absorb the colours that the dyes absorb undesirably. For instance, the cyan dye absorbs some green and blue light, whereas it should absorb only red light. Suppose we make a cyan-forming coupler that absorbs the same amount of green and blue as does the dye. Then the film will have the same absorption for green and blue all over—both in the parts where the coupler is converted into cyan dye and in the parts where the coupler is not changed and no cyan dye has been formed. The whole picture, in fact, appears as if it were made with a perfect

cyan dye having no absorption for green and blue but with a filter over it that absorbs green and blue all over the film. In the same way a magenta-forming coupler can be made that absorbs the same amount of blue-violet as the magenta dye does. If these coloured couplers are used to make a negative film, the print from it will not suffer at all from the incorrect absorptions of the cyan and magenta dyes.

Colour prints can be made from separation negatives prepared from colour transparencies or from complementary colour negatives. Two principal processes are employed for making prints: the *Carbro* process and the dye transfer, or imbibition, process. In the *Carbro* process, bromide prints are made from the separation negatives, and these are used to make colour prints—cyan, magenta, and yellow—in gelatin layers containing coloured pigments. The three coloured gelatin layers are then superimposed in register to make one picture. In the dye transfer process, the negatives are printed through the film base on to films coated with an ordinary slow emulsion dyed yellow and not containing any hardener. The images are developed with a developer such as alkaline pyrogallol, which hardens the gelatin where the image is developed. Then the unhardened emulsion is washed off with hot water and a relief image in hardened gelatin is obtained on the surface of the film. These relief images are known as *matrices*. To form a colour picture the matrices are soaked in solutions of appropriate dyes. Almost all the acid dyes can be used, but the choice of the dye depends upon its colour and its stability to light. The matrix printed from the red negative is first soaked in the cyan dye solution until it is saturated. Then the excess dye is rinsed off in a 1 per cent. solution of acetic acid and the matrix is squeegeed down in contact with a sheet of paper containing a mordant, such as is obtained by treating the paper with alum. In a few minutes the dye transfers and is adsorbed by the mordant in the paper, leaving the matrix almost free from dye. The matrix from the green separation negative is then soaked in a magenta dye, and this is transferred, care

being taken to register the image exactly with the cyan image already on the paper. Finally, the yellow image from the matrix made by blue light is transferred in the same way, and the colour picture is complete. When colour prints are made from complementary colour negatives, the process can be shortened because there is no need to make separation negatives. The bromide paper used for the *Carbro* process or the matrix film used for the dye transfer process can be made panchromatic by sensitizing dyes, and the separations can be made in preparing the bromide prints or the matrices direct from the complementary colour negative.

The new materials for colour photography which have been introduced during the last few years can perhaps be summarized best in the form of a table:

MATERIALS FOR MODERN COLOUR PROCESSES AVAILABLE COMMERCIALY IN THE UNITED STATES

For Still Pictures

Reversal film in rolls	
Kodachrome 35-mm film and Ansco color 35-mm film	
Ektachrome roll film and Ansco color roll film	
↓	↓
Kodachrome prints	Ansco Printon prints
Negative roll film	
Kodacolor roll film	
↓	
Kodacolor prints	
Sheet films	
Reversal: Kodachrome, Ektachrome, and Ansco color	
Negative: Kodacolor (with coloured couplers)	
↓	
	Dye transfer or <i>Carbro</i> prints

For Motion Pictures

16-mm and 8-mm reversal substandard films
 Kodachrome and Ansco color
 Kodachrome Commercial 16-mm film
 Kodachrome Duplicating 16-mm film.

ACKNOWLEDGMENT

Figures 1, 3, 4, and 6 are reproduced from *Photography*, by C. E. K. Mees, published by G. Bell & Sons Ltd.

The development of fluorine chemistry

H. J. EMELÉUS

Although compounds of fluorine have been known for nearly two hundred years, the element itself proved not only difficult to isolate but also extremely difficult to handle when it was at length obtained in the free state. For many years, knowledge of the chemistry of fluorine lagged far behind that of the other halogens, and it is only recently that, thanks to new techniques, fluorine and its compounds have become relatively familiar in the laboratory and—a still newer development—in industry, where they have already found important applications.

The history of fluorine is spread over almost two hundred years, but it was not until the early nineteenth century that the isolation of the element was attempted. Thus in 1808–16 Davy, having established the relationship between hydrogen chloride and hydrogen fluoride, electrolysed aqueous solutions of the latter, only to obtain hydrogen and oxygen. Chemical methods based on analogy with the preparation of chlorine also failed to yield fluorine, as did experiments on the electrolysis of fused metallic fluorides. Faraday's observation that anhydrous hydrogen fluoride was a non-conductor is specially notable among these early researches, because it was some thirty years later that Moissan, in 1886, first prepared fluorine by the electrolysis of the conducting solution formed by dissolving potassium fluoride in anhydrous hydrogen fluoride.

Moissan's work with fluorine is remarkable not only for the way in which the difficulties in producing and handling the new element were overcome at a time when laboratory technique was far less developed than now, but also for the wide range of reactions studied. The platinum or copper cell, filled with an electrolyte approximating in composition to $\text{KF} \cdot 12\text{HF}$ and fitted with platinum-iridium electrodes, gave a stream of fluorine which was allowed to react with many elements, including hydrogen, sulphur, selenium, tellurium, phosphorus, arsenic, carbon, boron, silicon, a large number of metals, and the other halogens. Many inorganic compounds were also examined and numerous new fluorides were discovered and characterized. Though this work was primarily directed towards filling a gap in systematic chemistry, it did in fact prepare the way for much that has happened since. For example, tetrafluoromethane was prepared and its inertness was recognized. Sulphur hexafluoride, which is now used as an insulating gas, was described. Perhaps Moissan's outlook on fluorine chemistry

may be summed in his own words: '*La recherche d'un nouveau corps simple est toujours très captivant*' [1]. It can seldom have happened that a chemist had a more attractive field to explore or made greater use of his opportunities.

The development of fluorine chemistry after Moissan's death was continued in his laboratory in Paris by Lebeau, and by Ruff in Germany. Until 1919 there was no major change in the method of generating the element, but laboratory techniques were gradually developed and the more reactive fluorine compounds, prepared from the free element, became better known. Ruff, for example, made a careful study of the halogen fluorides, which are all formed by interaction of the free halogens with fluorine. These substances, the formulae and boiling-points of which are shown in table I, are in some cases as reactive as fluorine itself but are in general more easily stored and handled, so that it is quite possible that they will be among the technically important substances of the future.

TABLE I

Fluoride	Boiling-point (°C)	Fluoride	Boiling-point (°C)	Fluoride	Boiling-point (°C)
ClF ..	-100	ClF_3 ..	11.3	—	—
BrF ..	20	BrF_3 ..	127	BrF_5 ..	40.5
—	—	—	—	IF_5 ..	97
—	—	—	—	IF_7 ..	4.5

Ruff also prepared and characterized the higher fluorides of the platinum metals among others, demonstrating how combination with fluorine excites the highest valency state of an element. The inert fluoride of nitrogen (NF_3), formed by the electrolysis of fused ammonium hydrogen fluoride, was likewise characterized, as were many other non-metallic fluorine derivatives. The isolation of the first fluorine oxide (F_2O) was due to Lebeau and Damiens, who showed that it is

formed in the reaction between fluorine and dilute aqueous sodium hydroxide. Later Ruff and his co-workers made a second and much less stable oxide (F_2O_2) by combination of the elements in a cooled tube through which an electrical discharge was passed. These examples are typical of results which were published in increasing numbers as fluorine became more accessible.

Interest in the chemistry of fluorine grew much wider as soon as improvements were made in the preparative methods. The first of these was the use of the electrolyte $KF.HF$, melting at $235^\circ C$, in place of $KF.12HF$. First introduced in 1919 by Argo, Mathers, Humiston, and Anderson [2], the new cells had the great advantage of cheapness, since a graphite anode was found to be suitable. Various constructional materials were used—Monel metal, copper, nickel, and magnesium—and although the fluorine was slightly contaminated with carbon fluorides and other impurities from the electrolyte, it became available for the first time to the modestly equipped research laboratory. Another equally useful type of cell, the so-called medium-temperature cell, with the electrolyte $KF.3HF$, was described by Lebeau and Damiens [3] in 1927. It operated in the temperature range $90-100^\circ C$ and in its early form had a nickel anode, since graphite was not suitable for this particular electrolyte. In later developments, however, special types of carbon have been substituted for nickel with a saving in cost and an improvement in operation.

The step from the laboratory fluorine generators to full-scale technical production has been less difficult than might have been anticipated. In Germany, attention was concentrated on developing the high-temperature cell using $KF.HF$, and an output of 50 tons of fluorine a month was reached. Individual cells carried about 2,500 ampères. In the United States and in England the medium-temperature cell was developed to a similar extent. Papers presented at the Chicago meeting of the American Chemical Society in 1946 [4] described such cells in detail, while models of the corresponding cells developed in England were shown at the exhibition arranged in London in 1947 in connection with the centenary celebrations of The Chemical Society.

The difficulties encountered in early work because of the great reactivity of fluorine have now been largely overcome, both in the laboratory and on a plant scale, by the general use of metals. Steel or copper is satisfactory at normal temperatures, but for higher temperatures nickel or Monel

metal is preferable. The storage of fluorine under pressure has presented special problems, largely because the normal type of compressor, in which contact with grease would occur, is out of the question. Two methods have been described: either the fluorine is liquefied and vaporized into a steel or nickel storage vessel at pressures up to about 25 atmospheres or, for lower pressures, a compressor of the diaphragm type has been used. The critical temperature of fluorine ($-129^\circ C$) precludes storage as a liquid, and for most major uses the gas is generated as required. The hydrogen-fluorine torch [5], which has been shown to give a self-fluxing weld for copper and other metals, does, however, require fluorine under pressure.

The last ten years have seen great developments not only in methods of producing fluorine but in its applications. Chief among these is the formation of fluorocarbons, the simplest of which (CF_4) was described by Moissan. The first reliable evidence of the formation of similar bodies of higher molecular weight was obtained by Ruff and Keim in 1930 [6] in studying the reaction between fluorine and carbon. This may first lead to an explosive fluoride (CF)_n, but if the carbon is first impregnated with 1 per cent. of a mercury salt a smooth reaction occurs. The chief product is (CF)_n, but decreasing quantities of fluorocarbons of higher molecular weight are also formed. The following data show that in the series C_nF_{2n+2} the boiling-points remain fairly close to those of the corresponding hydrocarbons. As would be expected, they are much lower than those of the chlorocarbons in spite of the comparable molecular weights. It is this volatility, great chemical inertness, and other valuable physical properties which make the higher fluorocarbons so interesting technically.

TABLE II
BOILING-POINTS

Number of C atoms	1	2	3	4	5	6	7	8	16
Hydrocarbon b.p. (°C)	-161	-88	-44	-0.5	36	68.98	125	287	
Fluorocarbon b.p. (°C)	-128	-78	-38	-5	22	51.82	104	240	

For producing useful fluorocarbons on a large scale the reaction between carbon and fluorine is unsuitable, because a large proportion of tetra-fluoromethane is formed, and no method is as yet available for converting this substance into compounds of higher boiling-point. One must

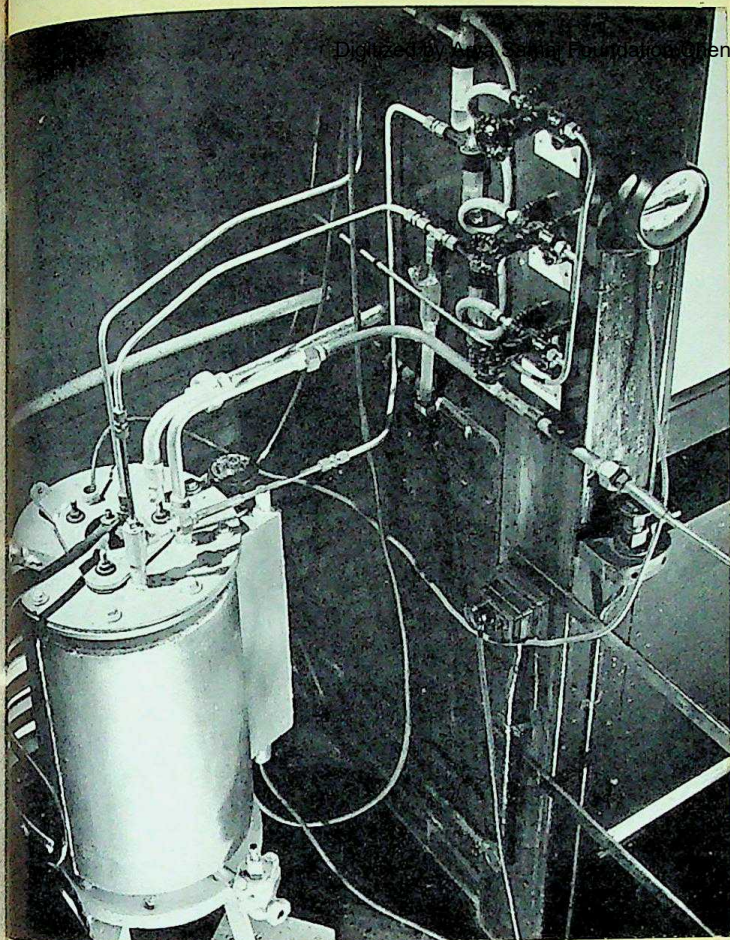


FIGURE 1 - Small medium-temperature fluorine cell assembled for laboratory work.

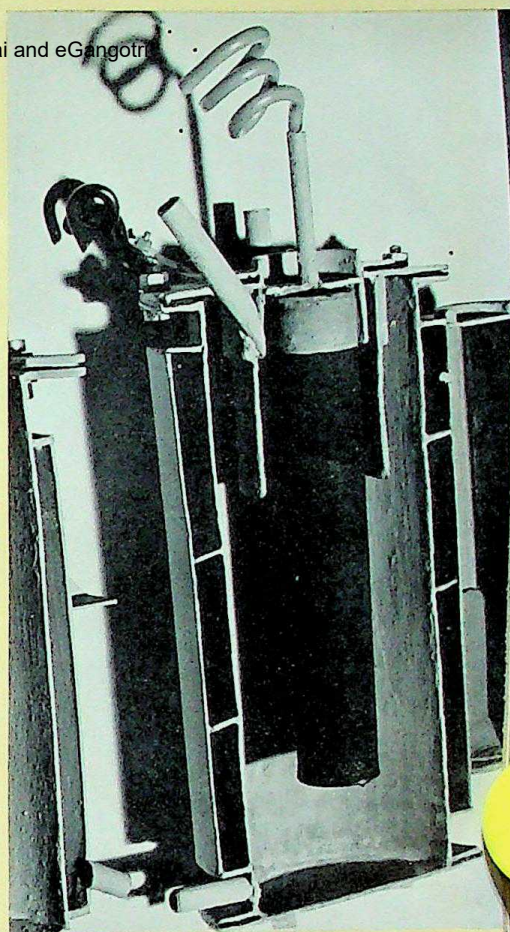


FIGURE 2 - Section of model of medium-temperature fluorine cell, showing carbon anode, diaphragm, and part of water jacket.

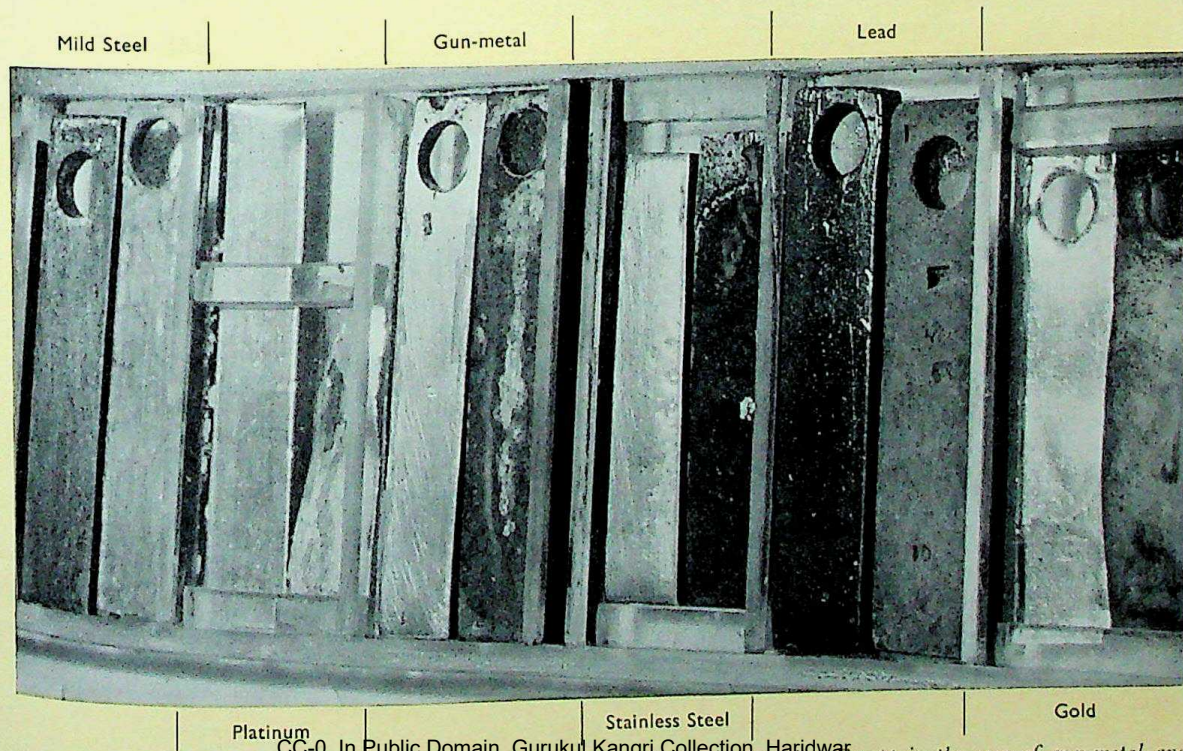


FIGURE 3 - Corrosion of metals exposed to fluorine free from hydrogen fluoride. Except in the case of gun-metal and platinum, which were exposed for only seven hours, the exposure was for one week at 400°C .

FIGURE 4 - Flow-meter for use with chlorine trifluoride. Note the compression unions for making glass-to-glass or glass-to-metal joints.

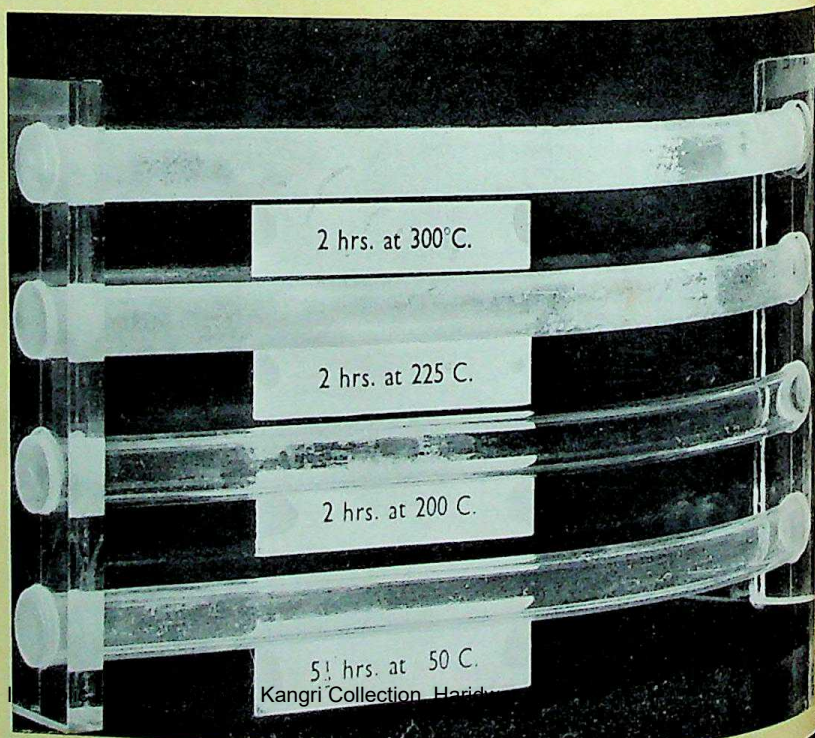
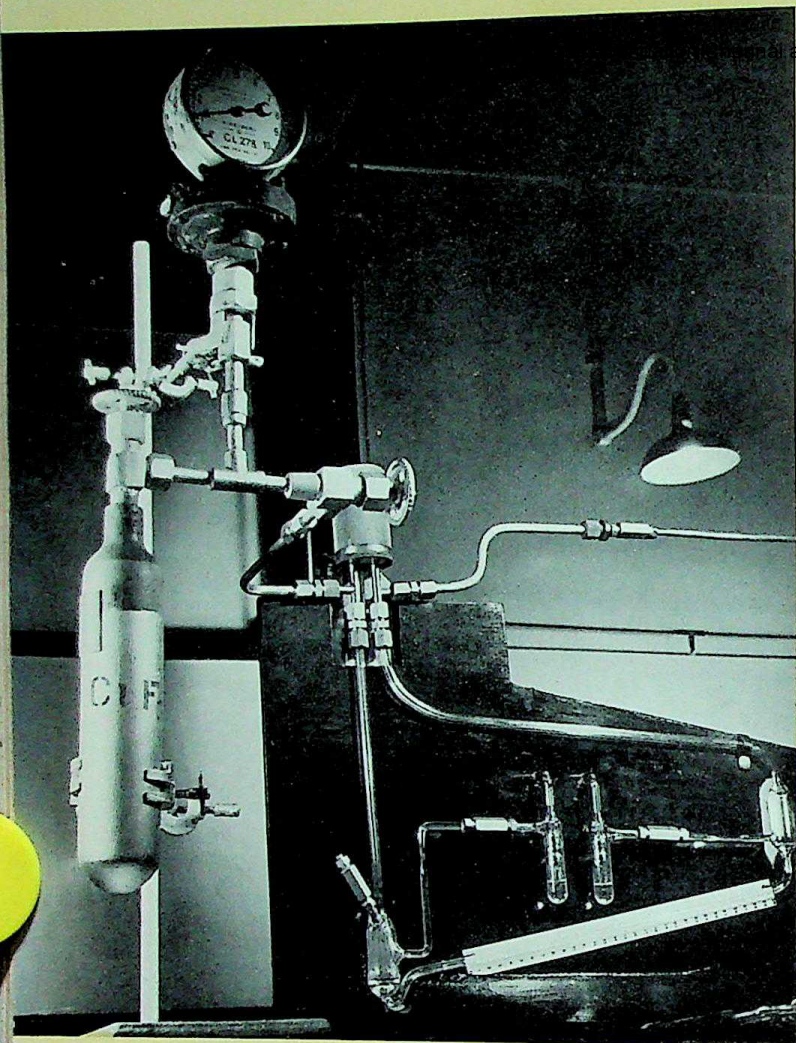
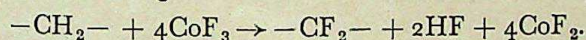


FIGURE 5 - Soda glass after exposure to fluorine free from hydrogen fluoride.

therefore turn to methods based on the direct replacement of hydrogen or chlorine by fluorine in a suitable carbon compound. This, as Moissan showed, is generally accompanied by a complete breakdown of the organic molecule if undiluted fluorine is used. The reaction may be moderated in various ways—by cooling, by dilution of the fluorine with nitrogen, or by the use of an inert solvent. All these expedients have been tried, but only two methods have so far given really satisfactory yields of fluorocarbons. These are:

1. Catalytic fluorination of an organic vapour at 200–350° C on a silver- or gold-plated copper catalyst with nitrogen dilution of both gas streams.
2. The reaction of the organic substance in the vapour or liquid phase at *ca.* 200–400° C with cobaltic or argentic fluoride.

In catalytic fluorinations it is almost certain that the action of the catalyst depends on the formation of a higher fluoride (e.g. AgF_2) by the fluorine and its subsequent reduction by the organic compound. In the second method the metal fluoride is first formed in the reactor by the action of fluorine ($2\text{CoF}_2 + \text{F}_2 = 2\text{CoF}_3$), after which the organic vapour is passed until the active metal fluoride is exhausted, the essential reaction being:



The cobaltous fluoride is then refluorinated and the cycle repeated.

These two methods have been studied extensively both in the United States and in Britain. Attention has been centred on producing materials boiling in the range 40–150° C, and comparatively non-volatile oils and greases. Table III shows some typical results obtained by Cady and his co-workers [7] by the catalytic fluorination

TABLE III

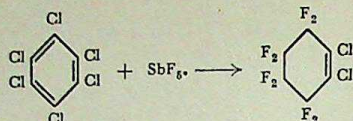
Material Fluorinated	Reaction Temp. (° C)	Product	Percentage Yield
C_6H_6	265	C_6F_{12}	58
<i>n</i> -Heptane	135	C_7F_{16}	62
$\text{C}_8\text{H}_8\text{CF}_3$	200	C_7F_{14}	85
$\text{C}_8\text{H}_4(\text{CF}_3)_2$	200	C_8F_{16}	87
Anthracene	300	$\text{C}_{14}\text{F}_{24}$	43
Light paraffin base lubricating oil	300	b.p. 150–200°/10 mm	12

method applied to materials of widely differing volatilities. It will be seen that in the fluorination of aromatic molecules the double bonds become saturated. Yields are fairly high, particularly for the simpler molecules, but incompletely fluorinated and breakdown products are always formed at the same time as the saturated fluorocarbon.

Yields so far reported for the second method, which covers a similar range of materials, are higher, and indicate that this is the more satisfactory process. With either method it is advantageous to work when possible with a partially pre-fluorinated material, because (a) yields can thereby be increased and (b) introduction of some of the fluorine atoms into the molecule with, say, hydrogen fluoride is cheaper. This point is well illustrated by recent work on heptane [8], which is first partially chlorinated photochemically, then partially fluorinated with anhydrous hydrogen fluoride in an autoclave reaction, and finally fully fluorinated with cobaltic or argentic fluoride.

The usefulness of fluorocarbons depends largely on their thermal stability and chemical inertness, particularly their high resistance to oxidation compared with that of hydrocarbons. Many are stable in air at temperatures above 300° C and are ideal as high-temperature lubricants. Most are known also to have good dielectric properties. As solvents, too, the more volatile show promise. They are non-inflammable and have quite specific properties. Thus aliphatic or aromatic hydrocarbons as well as alcohols are insoluble in them, whereas many halogenated organic compounds dissolve. The picture is, however, still far from complete, and the next few years will almost certainly add many hundreds to the list of known fluorocarbons and provide new examples of the uses of these materials.

In one respect the inertness of the fluorocarbons is a disadvantage, since it is not possible to apply the normal methods of organic synthesis with a view to building fluorocarbon skeletons into more complex structures. For this purpose it is better to work with an incompletely fluorinated material which has in its molecule a point of attack. For example, hexachlorobenzene can readily be completely fluorinated by the methods already described, and is then inert. If, however, it is made to react with antimony pentafluoride, it gives moderate yields of an octafluorinated product containing two residual chlorine atoms [8]. This, when oxidized with aqueous permanganate, yields perfluoroadipic acid, the carboxyl groups



of which are reactive and afford a means of building the fluorocarbon chain into other structures.

There are comparatively few general reactions other than those involving fluorine which are capable of fluorinating organic substances. This is largely due to the chemical differences between the normal halogenating reagents and the corresponding fluorides. Phosphorus trifluoride and sulphuryl fluoride, for example, do not act as fluorinating agents in the same way as the respective chlorides do as chlorinating agents, the fluorine atoms in them being more strongly bonded.

One reaction, however, which is specific for the production of fluorides has been widely used. This is the reaction of organic chloro-, bromo-, or iodo-bodies with antimony trifluoride. Discovered over fifty years ago by the Belgian chemist Swarts, this reaction has been extraordinarily useful in the preparation of both aliphatic and aromatic derivatives. It seldom brings about complete replacement of the original halogen by fluorine, and consequently the products contain both halogens (e.g. from CCl_4 one obtains under appropriate conditions CCl_3F , CCl_2F_2 , or CClF_3). A similar reaction occurs with a number of inorganic halides and oxyhalides (e.g. SiCl_4 yields chlorosilanes), and also with halogenated groups attached to an aromatic nucleus (e.g. $\text{C}_6\text{H}_5\text{CCl}_3 \rightarrow \text{C}_6\text{H}_5\text{CF}_3$). The ease of replacement varies widely from case to case; sometimes reaction occurs on refluxing, but in other cases an autoclave reaction is essential. It is also possible to use anhydrous hydrogen fluoride in these reactions, either alone or in conjunction with antimony fluoride. Organic halides will react with other inorganic fluorides (e.g. HgF_2 , AgF , TlF , KF), but these are less commonly employed and seem to be less suitable than the antimony salt for producing the mixed halogen derivatives.

Swarts' work resulted in the preparation of a surprisingly large number of simple mixed halides, but they attracted little attention until 1931, when Midgley proposed the use of carbon chloro-fluorides and related substances as refrigerants. These compounds—the Freons—proved to be practically non-toxic and inert, and had in addition excellent thermodynamic properties. They are widely used in refrigeration and air-

conditioning plant, where they have advantages over refrigerants such as ammonia. The Freons have a very useful range of boiling-points, as will be seen from the following typical figures:

	Boiling-point (°C)			
CHClF_2	..	..	..	-40.8
CCl_2F_2	..	..	..	-29.8
CHCl_2F	..	..	..	8.9
CCl_3F	..	..	..	23.7
$\text{CCl}_2\text{F}.\text{CCl}_2\text{F}$	..	..	..	47.6

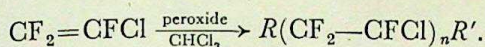
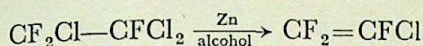
A further technical use of the Swarts reaction, or one of its modifications, is in the preparation of dyestuffs containing the CF_3 group as a substituent, the CCl_3 group attached to an aromatic nucleus being among those most readily fluorinated in this way.

The range of compounds prepared by Swarts included partially fluorinated olefines, and the successful preparation of polyethylene, or Polythene, not unnaturally directed attention to the possibility of obtaining polymers from chloro-fluoro- or fluoroethylene. Monomeric tetrafluoroethylene was first fully characterized by Ruff and Bretschneider [10], but its polymer was not described until 1941. Since this time the polymer has been produced on a technical scale, the monomer being first formed by the cracking of the commercially available Freon CF_2HCl at 650–800° C, when the main reaction follows the equation $2\text{CF}_2\text{HCl} \rightarrow \text{C}_2\text{F}_4 + 2\text{HCl}$.

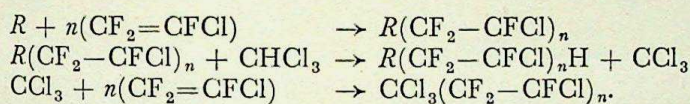
The yield of the gaseous monomer (b.p. -76.3°) may be as high as 90–95 per cent., although side reactions give minor amounts of polymers such as $\text{H}(\text{CF}_2)_n\text{Cl}$, where n may be as high as 14, and also similar cyclic products. The polymerization of the monomer is brought about in aqueous solution under pressure, and is catalysed by inorganic persulphates or other peroxy-bodies. The polymer is a white solid, remarkably stable to heat and oxidation—it can withstand temperatures of over 300° C for long periods without change—and also to most chemical reagents. Hot aqua regia and solvents at their boiling-points, for example, are without action upon it. The electrical properties are also good, for polytetrafluoroethylene combines a low power factor with a low dielectric constant. It is, however, a material which presents some difficulty in working, though mouldings (e.g. gaskets for chemical plant) have been widely used.

The polychlorofluoroethylenes, though less inert than the fully fluorinated material, also have applications as plastics and lubricants. Here again

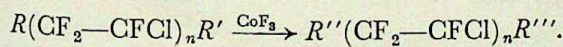
the starting material is the commercially available Freon 113 ($\text{CF}_2\text{Cl}-\text{CFCl}_2$), which is converted to the polymer by the following stages [12]:



The first stage of the reaction occurs quantitatively at the temperature of boiling alcohol, the volatile monomer produced being continuously removed. The monomer may be stabilized in storage by the addition of substances such as tributylamine: its polymerization occurs readily and will yield solid products. When it is desired to produce liquid polymers for use as lubricants the reaction is carried out in chloroform with benzoyl peroxide as a catalyst. The polymerization is a chain reaction, and both the peroxide and the solvent are believed to furnish terminal groups for the chain-like molecules. The whole process may be represented by a mechanism in which the peroxide first dissociates thermally forming a free radical R , which then reacts further:



The presence of reactive atoms in the terminal groups of the polymer necessitates a final fluorination of the product of the above reactions: this is done by heating the crude polymer with cobalt trifluoride at 200°C . Final distillation yields a



material with a chain length of about twelve carbon atoms which has excellent lubricating properties, and also a range of greases of higher molecular weight.

Of the more familiar fluorine compounds

anhydrous hydrogen fluoride is by far the most important. Some of its major uses have already been mentioned, but there are others which are comparatively new and seem likely to be of great importance. For example, it readily attaches to olefinic and acetylenic bonds in organic compounds. It is also a good catalyst for organic alkylation and acylation reactions, and has been used on a considerable scale in synthesizing high-octane petrol by alkylation. Yet another potential use arises from the recent publication of Simons and McArthur [13], who have shown that aromatic compounds in hydrogen fluoride solution may be oxidized by molecular oxygen under pressure in the presence of oxygen carriers such as arsenious oxide, ferric oxide, or silver oxide. Benzene, for example, is oxidized to phenol in very high yield in this medium.

Any attempt to assess the future importance of fluorine and its compounds can be only a matter of speculation. That fluorine compounds possess properties differing greatly from those of compounds of the other halogens is clear. The explanation of these differences will tax the resourcefulness of theoretical chemists. For the research worker, too, there are many problems to be solved before it is

possible to synthesize and study molecules fashioned so as to contain fluorocarbon radicals in any desired position. When this can be done it may well be that valuable new physiological actions will be observed. The industrial uses of fluorine compounds are already considerable and have been referred to in this article only in part. The chief raw material, calcium fluoride, is abundant, and there is good reason to think that the new industry which has recently grown up will continue to expand, giving us new plastics, solvents, lubricants, insecticides, and pharmaceuticals.

REFERENCES

- [1] MOISSAN. *Le Fluor et ses Composés*, p. viii.
- [2] ARGO, MATHERS, HUMISTON, and ANDERSON. *J. Physical Chem.*, 1919, **23**, 348.
- [3] LEBEAU and DAMIENS. *Comp. rend.*, 1925, **181**, 917.
- [4] See *Ind. Eng. Chem.*, 1947, **39**, 235-433.
- [5] PRIEST and GROSSE. *Ibid.*, 1947, **39**, 431.
- [6] *Z. anorg. Chem.*, 1930, **192**, 249.
- [7] CADY, GROSSE, BARBER, BRUGER, and SHELDON. *Ind. Eng. Chem.*, 1947, **39**, 290.
- [8] MCBEE, HOLTON, EVANS, ALBERTS, WELCH, LIGETT, SCHREYER, and KRANTZ. *Ibid.*, 1947, **39**, 310.
- [9] MCBEE, WISEMAN, and BACHMAN. *Ibid.*, 1947, **39**, 415.
- [10] *Z. anorg. Chem.*, 1939, **210**, 173.
- [11] PARK, BENNING, DOWNING, LAUCIUS, and MCHARNES. *Ind. Eng. Chem.*, 1947, **39**, 354.
- [12] MILLER, DETTMEN, EHRENFELD, and PROBER. *Ibid.*, 1947, **39**, 333.
- [13] SIMONS and MCARTHUR. *Ibid.*, 1947, **39**, 364.

Boyle's law

DOUGLAS McKIE

The celebrated generalization known as Boyle's law is still often referred to as Mariotte's law, and even by Boyle's own countrymen it is sometimes called the law of Boyle and Mariotte. It was announced by Boyle in 1662 as a result of extensive and carefully executed experiments. Mariotte's work was much later in date and was based on very few experiments.

In 1660 the Honourable Robert Boyle published at Oxford his *New Experiments Physico-Mechanicall, Touching The Spring of the Air, and its Effects (Made, for the most part, in a New Pneumatical Engine)*, etc. In this remarkable book Boyle described experiments on the weight and pressure of the air, vacuum, combustion and respiration, the solubility of air in water and its inclusion in mercury, the compressibility of water, the ebullition of liquids at ordinary temperatures under reduced pressure, and many other incidental matters. The air-pump with which the experiments were made was constructed for him by Robert Hooke, 'the greatest mechanick of the age,' who was then his paid assistant and whose help he gratefully acknowledged. The experimental work was done during the years 1658 and 1659, the book, written in the form of a letter to Lord Dungarvan, Boyle's nephew, being subscribed at the end '*Becon's-field this 20th of December, 1659.*'

Among the forty-three numbered experiments, exclusive of many subsidiary 'tryals,' Boyle justly drew special attention to the seventeenth, 'whereof the satisfactory tryal was the principal Fruit I promis'd my self from our Engine.' Briefly, Boyle arranged to include in the receiver of the air-pump the so-called Torricellian apparatus, in which a tube, about one metre long and 7 mm in diameter, closed at one end and filled with mercury, was inverted over mercury in a small cylindrical bowl, the end of the tube projecting through the cover of the receiver and its passage being made airtight with melted 'diachylon.' On evacuating the receiver, Boyle found that the mercury in the tube, which, of course, had already fallen to its normal height of about 69 cm, began to fall further, its height decreasing at every stroke of the pump. 'This experiment,' wrote Boyle, 'was a few days after repeated in the presence of those excellent and deservedly Famous Mathematick Professors, Dr Wallis, Dr Ward, and Mr Wren, who were pleased to Honor it with their Presence.'

On this occasion the mercury in the tube fell to within 2.5 cm of that in the cylindrical bowl in which the tube was inverted. Boyle was, however, troubled with 'some little Particles of Air engag'd among those of the Quick-silver,' and therefore the mercury did not fully regain its original height when air was readmitted to the receiver.

The expected result had, however, been obtained; for removal of air from the receiver had shown that the mercury in the Torricellian tube was 'in an *Æquilibrium* with the Cylinder of Air, suppos'd to reach from the adjacent Mercury to the top of the Atmosphere.'

In evacuating the receiver Boyle had begun to consider the reduced 'spring of the air' and he had spoken of the 'pressure of the air'; he regretted that he had so far not been able to correlate 'the pressure of the air' in the receiver with 'the gravity of Quick-silver' in the tube, although he felt that 'in our Experiment there are diverse things given, that may be made use of towards such a discovery.' Further experiments were made, which we shall mention later, and their results were reported to the Royal Society in 1661.

In 1661 Boyle's opinions on the Torricellian experiment were criticized by Franciscus Linus in a book published in London and entitled *Tractatus de corpore inseparabilitate*, etc. The author, although not denying the weight and spring of the air, contended that these were insufficient to sustain the column of mercury, which, he alleged, was kept in suspension by a curious 'funiculus' or thin substance, which held it to the top of the tube.

It was in replying to Linus's criticisms in *A Defence Of the Doctrine touching the Spring and Weight Of the Air*, etc., appended to the second edition of the *New Experiments* (London, 1662), that Boyle first published the law with which his name is associated. He took a long glass tube, bent into a U-shape, with a short closed limb and a long open limb, 'which Tube, though of a pretty bigness, was so long, that the Cylinder whereof the shorter leg

of it consisted admitted a list of Paper, which had before been divided into 12 Inches and their quarters, and the longer leg admitted another list of Paper of divers foot in length, and divided after the same manner: then Quicksilver being poured in to fill up the bended part of the Glass, that the surface of it in either leg might rest in the same Horizontal line, . . . there was more and more Quicksilver poured into the longer Tube; and notice being watchfully taken how far the Mercury was risen in that longer Tube, when it appeared to have ascended to any of the divisions in the shorter Tube, the several Observations that were thus successively made, and as they were made set down, afforded us the ensuing Table.' (See figure 1.)

The 'Hypothesis, that supposes the pressures and expansions to be in reciprocal proportion' had been suggested to Boyle by

A Table of the Condensation of the Air.

A	A	B	C	D	E
48	12	00		$29\frac{2}{3}$	$29\frac{2}{3}$
46	$11\frac{1}{2}$	$01\frac{1}{4}$		$30\frac{1}{6}$	$30\frac{1}{6}$
44	11	$02\frac{1}{2}$		$31\frac{1}{3}$	$31\frac{1}{3}$
42	$10\frac{1}{2}$	$04\frac{1}{2}$		$33\frac{1}{2}$	$33\frac{1}{2}$
40	10	$06\frac{1}{2}$		$35\frac{1}{2}$	$35\frac{1}{2}$
38	$9\frac{1}{2}$	$07\frac{1}{2}$		37--	$36\frac{1}{2}$
36	9	$10\frac{2}{3}$		$39\frac{1}{6}$	$38\frac{2}{3}$
34	$8\frac{1}{2}$	$12\frac{1}{2}$		$41\frac{1}{6}$	$41\frac{1}{6}$
32	8	$15\frac{1}{6}$		$44\frac{1}{6}$	$43\frac{1}{6}$
30	$7\frac{1}{2}$	$17\frac{1}{6}$		$47\frac{1}{6}$	$46\frac{1}{6}$
28	7	$21\frac{1}{6}$		$50\frac{1}{6}$	50--
26	$6\frac{1}{2}$	$25\frac{1}{6}$		$54\frac{1}{6}$	$53\frac{1}{3}$
24	6	$29\frac{1}{6}$		$58\frac{1}{6}$	$58\frac{1}{6}$
23	$5\frac{1}{2}$	$32\frac{1}{2}$		$61\frac{1}{6}$	$60\frac{2}{3}$
22	$5\frac{1}{2}$	$34\frac{1}{6}$		$64\frac{1}{6}$	$63\frac{1}{6}$
21	$5\frac{1}{2}$	$37\frac{1}{6}$		$67\frac{1}{6}$	$66\frac{1}{6}$
20	5	$41\frac{2}{3}$		$70\frac{1}{6}$	70--
19	$4\frac{1}{2}$	45--		$74\frac{1}{6}$	$73\frac{1}{6}$
18	$4\frac{1}{2}$	$48\frac{1}{6}$		$77\frac{1}{6}$	$77\frac{1}{6}$
17	$4\frac{1}{2}$	$53\frac{1}{6}$		$82\frac{1}{6}$	$82\frac{1}{6}$
16	4	$58\frac{1}{6}$		$87\frac{1}{6}$	$87\frac{1}{6}$
15	$3\frac{1}{2}$	$63\frac{1}{6}$		$93\frac{1}{6}$	$93\frac{1}{6}$
14	$3\frac{1}{2}$	$71\frac{1}{6}$		$100\frac{2}{6}$	$99\frac{7}{6}$
13	$3\frac{1}{2}$	$78\frac{1}{6}$		$107\frac{1}{6}$	$107\frac{1}{6}$
12	3	$88\frac{2}{6}$		$117\frac{2}{6}$	$116\frac{8}{6}$

FIGURE 1 - Table of condensation, from the Defence.

A Table of the Rarefaction of the Air.

A	B	C	D	E
1	00	0	$29\frac{2}{3}$	$29\frac{2}{3}$
$1\frac{1}{4}$	10	$\frac{1}{4}$	$19\frac{1}{2}$	$19\frac{1}{2}$
2	$15\frac{1}{8}$	$\frac{1}{8}$	$14\frac{3}{8}$	$14\frac{3}{8}$
3	$20\frac{1}{8}$	$\frac{1}{8}$	$9\frac{3}{8}$	$9\frac{1}{2}$
4	$22\frac{1}{4}$	$\frac{1}{4}$	$7\frac{1}{4}$	$7\frac{1}{6}$
5	$24\frac{1}{2}$	$\frac{1}{2}$	$5\frac{1}{2}$	$5\frac{2}{3}$
6	$24\frac{3}{4}$	$\frac{3}{4}$	$4\frac{3}{4}$	$4\frac{2}{3}$
7	$25\frac{1}{2}$	1	$4\frac{1}{2}$	$4\frac{1}{4}$
8	$26\frac{1}{2}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$
9	$26\frac{3}{4}$	$1\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{3}$
10	$26\frac{1}{2}$	2	$3\frac{1}{2}$	$2\frac{1}{2}$
12	$27\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$
14	$27\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$
16	$27\frac{1}{2}$	3	$2\frac{1}{2}$	$2\frac{1}{2}$
18	$27\frac{3}{4}$	$3\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$
20	$28\frac{1}{2}$	4	$1\frac{1}{2}$	$1\frac{1}{2}$
24	$28\frac{3}{4}$	$4\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$
28	$28\frac{1}{2}$	$5\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$
32	$28\frac{3}{4}$	$6\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$

FIGURE 2 - Table of rarefaction, from the Defence.

- AA. The number of equal spaces in the shorter leg, that contained the same parcel of Air diversly extended.
- B. The height of the Mercurial Cylinder in the longer leg, that compress'd the Air into those dimensions.
- C. The height of a Mercurial Cylinder that counterbalanc'd the pressure of the Atmosphere.
- D. The Aggregate of the two last Columns B and C, exhibiting the pressure sustained by the included Air.
- E. What that pressure should be according to the Hypothesis, that supposes the pressures and expansions to be in reciprocal proportion.

Richard Townley, as Boyle himself stated at this point; but Townley did not complete his promised 'Discourse' or, so far as is known, make any experiments. Accordingly, continued Boyle, 'our present design invites us to present the Reader with that which follows'; and he went on to report the results of a series of experiments on rarefaction. A glass tube open at both ends was taken and a 'list of Paper divided into Inches and half quarters' was pasted along its length. The tube was then thrust down into a larger tube almost filled with mercury and then sealed at the upper end with wax so that there was about 2.5 cm of air included. The tube was raised by degrees and the height of the mercury column in it measured together

To

with the length of the included and steadily dilating column of air. Results were given in the table on page 149 (figure 2).

Boyle had previously given an account of the experiments on 'condensation' to the Royal Society on 11th and 18th September, 1661, and the minutes of the meeting held on the latter date record that 'Mr. Boyle brought in his account in writing of the experiment made by him of the compression of air with the quicksilver tube; which was ordered to be registered.' The original Register Book in the archives of the Royal Society contains this account in the form of a table of experimental results identical with that already quoted and published later in 1662 (see figure 3).

We have no record of Townley's correspondence with Boyle about his hypothesis. Hooke later referred to Boyle's 'deservedly famous Pneumatick Book' and to 'Mr. Townly's Hypothesis' and described some experiments that he had made on 2nd August, 1661, 'having lately heard of Mr. Townly's Hypothesis,' but made no claim to priority over Boyle (*Micrographia*, London, 1665, pp. 222-8). Hooke reported to the Royal Society on 10th December, 1662, the results of experiments on rarefaction, and the account, ordered to be registered, is extant in the archives of the Society.

Thus Boyle's work was published in complete form in 1662. The *Defence* was well known, and a further edition followed in 1663 in Latin (*Defensio doctrinae*, etc., London, 1663). Other Latin editions were published at Rotterdam in 1669 and Geneva in 1677, all before the publication of Mariotte's book.

Edmé Mariotte was a member of the French *Académie des Sciences*. The work said to contain his formulation of the law connecting the pressure and volume of air is stated to have been published in 1676. Long search in the literature has so far not confirmed this date.

Mariotte's *De la Nature de l'Air* occurs as the second essay in his *Essays de Phisique*, which bears only a general title-page or rather a half-title without place or date of publication or author's name, covering a work comprising four essays, every one of which has a separate title-page with place and date of publication and author's name and separate pagination. The first three essays bear the date of 1679 on their title-pages; the fourth is dated 1681.

It is the second essay that concerns us. The experiments—only six in all—resemble Boyle's. Mariotte began by stating that air was heavy, as indicated by the Torricellian experiment, and

An Experimentall Account of y^e Compression of Aire.

Made by Edm^d Boyle

Inches of Aire to be compressed)	Weight of mercury to compress that Aire	Weight of Aire to be compressed	Weight of Aire to be compressed
12	29 1/2	00	29 1/2
11 1/2	29 1/2	12 1/2	30 1/2
11	29 1/2	25 1/2	31 1/2
10 1/2	29 1/2	38 1/2	32 1/2
10	29 1/2	51 1/2	33 1/2
9 1/2	29 1/2	64 1/2	34 1/2
9	29 1/2	77 1/2	35 1/2
8 1/2	29 1/2	90 1/2	36 1/2
8	29 1/2	103 1/2	37 1/2
7 1/2	29 1/2	116 1/2	38 1/2
7	29 1/2	129 1/2	39 1/2
6 1/2	29 1/2	142 1/2	40 1/2
6	29 1/2	155 1/2	41 1/2
5 1/2	29 1/2	168 1/2	42 1/2
5	29 1/2	181 1/2	43 1/2
4 1/2	29 1/2	194 1/2	44 1/2
4	29 1/2	207 1/2	45 1/2
3 1/2	29 1/2	220 1/2	46 1/2
3	29 1/2	233 1/2	47 1/2
2 1/2	29 1/2	246 1/2	48 1/2
2	29 1/2	259 1/2	49 1/2
1 1/2	29 1/2	272 1/2	50 1/2
1	29 1/2	285 1/2	51 1/2
3/4	29 1/2	298 1/2	52 1/2
1/2	29 1/2	311 1/2	53 1/2
1/4	29 1/2	324 1/2	54 1/2
1/8	29 1/2	337 1/2	55 1/2
1/16	29 1/2	350 1/2	56 1/2
1/32	29 1/2	363 1/2	57 1/2
1/64	29 1/2	376 1/2	58 1/2
1/128	29 1/2	389 1/2	59 1/2
1/256	29 1/2	402 1/2	60 1/2
1/512	29 1/2	415 1/2	61 1/2
1/1024	29 1/2	428 1/2	62 1/2
1/2048	29 1/2	441 1/2	63 1/2
1/4096	29 1/2	454 1/2	64 1/2
1/8192	29 1/2	467 1/2	65 1/2
1/16384	29 1/2	480 1/2	66 1/2
1/32768	29 1/2	493 1/2	67 1/2
1/65536	29 1/2	506 1/2	68 1/2
1/131072	29 1/2	519 1/2	69 1/2
1/262144	29 1/2	532 1/2	70 1/2
1/524288	29 1/2	545 1/2	71 1/2
1/1048576	29 1/2	558 1/2	72 1/2
1/2097152	29 1/2	571 1/2	73 1/2
1/4194304	29 1/2	584 1/2	74 1/2
1/8388608	29 1/2	597 1/2	75 1/2
1/16777216	29 1/2	610 1/2	76 1/2
1/33554432	29 1/2	623 1/2	77 1/2
1/67108864	29 1/2	636 1/2	78 1/2
1/134217728	29 1/2	649 1/2	79 1/2
1/268435456	29 1/2	662 1/2	80 1/2
1/536870912	29 1/2	675 1/2	81 1/2
1/1073741824	29 1/2	688 1/2	82 1/2
1/2147483648	29 1/2	701 1/2	83 1/2
1/4294967296	29 1/2	714 1/2	84 1/2
1/8589934592	29 1/2	727 1/2	85 1/2
1/17179869184	29 1/2	740 1/2	86 1/2
1/34359738368	29 1/2	753 1/2	87 1/2
1/68719476736	29 1/2	766 1/2	88 1/2
1/137438953472	29 1/2	779 1/2	89 1/2
1/274877906944	29 1/2	792 1/2	90 1/2
1/549755813888	29 1/2	805 1/2	91 1/2
1/1099511627776	29 1/2	818 1/2	92 1/2
1/2199023255552	29 1/2	831 1/2	93 1/2
1/4398046511104	29 1/2	844 1/2	94 1/2
1/8796093022208	29 1/2	857 1/2	95 1/2
1/17592186044416	29 1/2	870 1/2	96 1/2
1/35184372088832	29 1/2	883 1/2	97 1/2
1/70368744177664	29 1/2	896 1/2	98 1/2
1/140737488355328	29 1/2	909 1/2	99 1/2
1/281474976710656	29 1/2	922 1/2	100 1/2
1/562949953421312	29 1/2	935 1/2	101 1/2
1/1125899906842624	29 1/2	948 1/2	102 1/2
1/2251799813685248	29 1/2	961 1/2	103 1/2
1/4503599627370496	29 1/2	974 1/2	104 1/2
1/9007199254740992	29 1/2	987 1/2	105 1/2
1/18014398509481984	29 1/2	1000 1/2	106 1/2
1/36028797018963968	29 1/2	1013 1/2	107 1/2
1/72057594037927936	29 1/2	1026 1/2	108 1/2
1/144115188075855872	29 1/2	1039 1/2	109 1/2
1/288230376151711744	29 1/2	1052 1/2	110 1/2
1/576460752303423488	29 1/2	1065 1/2	111 1/2
1/1152921504606846976	29 1/2	1078 1/2	112 1/2
1/2305843009213693952	29 1/2	1091 1/2	113 1/2
1/4611686018427387904	29 1/2	1104 1/2	114 1/2
1/9223372036854775808	29 1/2	1117 1/2	115 1/2
1/18446744073709551616	29 1/2	1130 1/2	116 1/2
1/36893488147419103232	29 1/2	1143 1/2	117 1/2
1/73786976294838206464	29 1/2	1156 1/2	118 1/2
1/147573952589676412928	29 1/2	1169 1/2	119 1/2
1/295147905179352825856	29 1/2	1182 1/2	120 1/2
1/590295810358705651712	29 1/2	1195 1/2	121 1/2
1/1180591620717411303424	29 1/2	1208 1/2	122 1/2
1/2361183241434822606848	29 1/2	1221 1/2	123 1/2
1/4722366482869645213696	29 1/2	1234 1/2	124 1/2
1/9444732965739290427392	29 1/2	1247 1/2	125 1/2
1/18889465931478580854784	29 1/2	1260 1/2	126 1/2
1/37778931862957161709568	29 1/2	1273 1/2	127 1/2
1/75557863725914323419136	29 1/2	1286 1/2	128 1/2
1/151115727451828646838272	29 1/2	1299 1/2	129 1/2
1/302231454903657293676544	29 1/2	1312 1/2	130 1/2
1/604462909807314587353088	29 1/2	1325 1/2	131 1/2
1/1208925819614629174706176	29 1/2	1338 1/2	132 1/2
1/2417851639229258349412352	29 1/2	1351 1/2	133 1/2
1/4835703278458516698824704	29 1/2	1364 1/2	134 1/2
1/9671406556917033397649408	29 1/2	1377 1/2	135 1/2
1/19342813113834066795298816	29 1/2	1390 1/2	136 1/2
1/38685626227668133590597632	29 1/2	1403 1/2	137 1/2
1/77371252455336267181195264	29 1/2	1416 1/2	138 1/2
1/154742504910672534362390528	29 1/2	1429 1/2	139 1/2
1/309485009821345068724781056	29 1/2	1442 1/2	140 1/2
1/618970019642690137449562112	29 1/2	1455 1/2	141 1/2
1/1237940039285380274899124224	29 1/2	1468 1/2	142 1/2
1/2475880078570760549798248448	29 1/2	1481 1/2	143 1/2
1/4951760157141521099596496896	29 1/2	1494 1/2	144 1/2
1/9903520314283042199192993792	29 1/2	1507 1/2	145 1/2
1/19807040628566084398385987584	29 1/2	1520 1/2	146 1/2
1/39614081257132168796771975168	29 1/2	1533 1/2	147 1/2
1/79228162514264337593543950336	29 1/2	1546 1/2	148 1/2
1/158456325028528675187087900672	29 1/2	1559 1/2	149 1/2
1/316912650057057350374175801344	29 1/2	1572 1/2	150 1/2
1/633825300114114700748351602688	29 1/2	1585 1/2	151 1/2
1/1267650600228229401496703205376	29 1/2	1598 1/2	152 1/2
1/2535301200456458802993406410752	29 1/2	1611 1/2	153 1/2
1/5070602400912917605986812821504	29 1/2	1624 1/2	154 1/2
1/10141204801825835211973625643008	29 1/2	1637 1/2	155 1/2
1/20282409603651670423947251286016	29 1/2	1650 1/2	156 1/2
1/40564819207303340847894502572032	29 1/2	1663 1/2	157 1/2
1/81129638414606681695789005144064	29 1/2	1676 1/2	158 1/2
1/162259276829213363391578010288128	29 1/2	1689 1/2	159 1/2
1/324518553658426726783156020576256	29 1/2	1702 1/2	160 1/2
1/649037107316853453566312041152512	29 1/2	1715 1/2	161 1/2
1/1298074214633706907132624082305024	29 1/2	1728 1/2	162 1/2
1/2596148429267413814265248164610048	29 1/2	1741 1/2	163 1/2
1/5192296858534827628530496329220096	29 1/2	1754 1/2	164 1/2
1/10384593717069655257060992658440192	29 1/2	1767 1/2	165 1/2
1/20769187434139310514121985316880384	29 1/2	1780 1/2	166 1/2
1/41538374868278621028243970633760768	29 1/2	1793 1/2	167 1/2
1/83076749736557242056487941267521536	29 1/2	1806 1/2	168 1/2
1/166153499473114484112975882535043072	29 1/2	1819 1/2	169 1/2
1/332306998946228968225951765070086144	29 1/2	1832 1/2	170 1/2
1/664613997892457936451903530140172288	29 1/2	1845 1/2	171 1/2
1/1329227995784915872903807060280344576	29 1/2	1858 1/2	172 1/2
1/2658455991569831745807614120560689152	29 1/2	1871 1/2	173 1/2
1/5316911983139663491615228241121378304	29 1/2	1884 1/2	174 1/2
1/10633823966279326983230456482242756608	29 1/2	1897 1/2	175 1/2
1/21267647932558653966460912964485513216	29 1/2	1910 1/2	176 1/2
1/42535295865117307932921825928971026432	29 1/2	1923 1/2	177 1/2
1/85070591730234615865843651857942052864	29 1/2	1936 1/2	178 1/2
1/170141183460469231731687303715884105728	29 1/2	1949 1/2	179 1/2
1/340282366920938463463374607431768211456	29 1/2	1962 1/2	180 1/2
1/680564733841876926926749214863536422912	29 1/2	1975 1/2	181 1/2
1/1361129467683753853853498429727072845824	29 1/2	1988 1/2	182 1/2
1/272225893536750770770699685945414569152	29 1/2	2001 1/2	183 1/2
1/544451787073501541541399371890829138304	29 1/2	2014 1/2	184 1/2
1/1088903574147003083082798743781658276608	29 1/2	2027 1/2	185 1/2
1/2177807148294006166165597487563316553216	29 1/2	2040 1/2	186 1/2
1/4355614296588012332331194975126633106432	29 1/2	2053 1/2	187 1/2
1/8711228593176024664662389950253266212864	29 1/2	2066 1/2	188 1/2
1/17422457186352049329324779900506532425728	29 1/2	2079 1/2	189 1/2
1/34844914372704098658649559801013064851456	29 1/2	2092 1/2	190 1/2
1/69689828745408197317299119602026129702912	29 1/2	2105 1/2	191 1/2
1/139379657490816394634598239204052259405824	29 1/2	2118 1/2	192 1/2
1/278759314981632789269196478408104518811648	29 1/2	2131 1/2	193 1/2
1/557518629963265578538392956816209037623296	29 1/2	2144 1/2	194 1/2
1/1115037259926531157076785913632418075246592	29 1/2	2157 1/2	195 1/2
1/2230074519853062314153571827264836150493184	29 1/2	2170 1/2	196

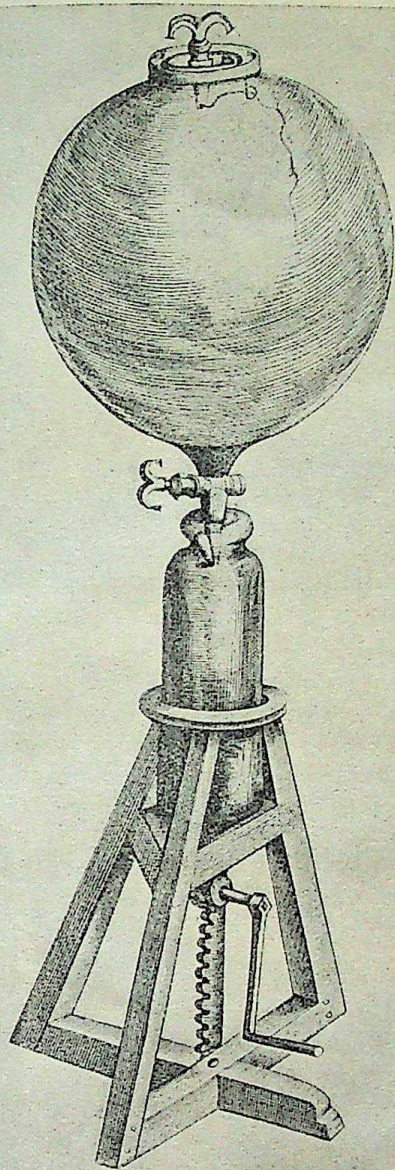


FIGURE 4 - Boyle's pump, from the *New Experiments* (1660).

correct when the experiment was made. Halving the weight of the mercury column from its normal length had dilated the air to twice its former extent.

Mariotte added that he had made other similar and successful experiments. It may be noted that the first two dealt with the expansion of air. More sensitive experiments, he said, could be made in a bent tube, the shorter and closed limb of which contained some air over mercury, the longer and open limb containing mercury to the same height as that in the closed tube. He then described four experiments on compression,

similar to those of Boyle, whom he nowhere mentioned. In the first, 30 cm of air were compressed to 20 cm by adding mercury to the open limb to a height of 35 cm above that in the closed limb, the total weight of mercury being then $70 + 35$, or 105, and 105 being to 70 as 30 to 20. In three similar experiments the lengths of the mercury column corresponding to reductions of the column of air to a half, a third, and a quarter of its original length were determined and were found to agree with the predicted values, namely, 70, 140, and 210 cm of mercury in addition to the normal 70 cm corresponding to the weight of the atmosphere. Thus the total number of experiments reported by Mariotte was six, two for rarefaction and four for compression, and all related to simple cases. It is not an impressive result as compared with Boyle's forty-four determinations. Moreover, it will be seen that Mariotte's experimental figures have been calculated beforehand from the hypothesis for six simple cases, and that the results serve rather to illustrate the hypothesis than to test its correctness in an exhaustive manner.

Mariotte's essay contains many phrases recalling those of Boyle; the reader gets the impression that its author was familiar with Boyle's work and that he was not making an independent discovery but rather illustrating one already made by another.

It cannot therefore be questioned that Boyle first formulated the law that should properly be known by his name alone, and that he published his work in 1662, embodying experimental data to show 'the pressures and expansions to be in reciprocal proportion.' Mariotte's work was both later in time and inferior in quality.

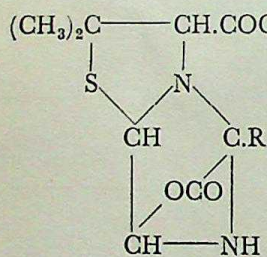
The date of Mariotte's essay, as we have noted, is widely given as 1676. The *Bibliothèque Nationale*, however, possesses no copy of the work earlier than that of 1679, when it appeared as the second essay in the *Essays de Phisique*. The *Histoire* of the *Académie* does not mention it until 1679. The *Journal des Sçavans* contains no earlier reference than 1679, when the essay was reviewed in the issue for 20th November and included in the list of books published in 1679 given at the end of the volume of the *Journal* for that year. In these circumstances no date earlier than 1679 can safely be assigned to Mariotte's essay at present. The date 1676 may have crept in by some misprint: one such does indeed occur in the Amsterdam reprint of the *Journal des Sçavans* for 1679, where the list of books published in 1679 includes the first three essays, but the review of the first essay gives the date as 1676.

Chemical properties and structure of the penicillins (*concluded*)

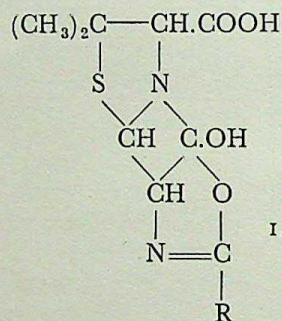
E. CHAIN

In the continuation of his article, the first part of which was published in our July issue, Dr Chain describes the research which led to the final elucidation of the structure of the penicillin molecule. At a comparatively early stage this resolved itself into a choice between a β -lactam and a thiazolidine-oxazolone structure, the former ultimately proving to be the correct one. He discusses also attempts to synthesize penicillin either partially or completely.

It may be mentioned that, in addition to the β -lactam and thiazolidine-oxazolone structures, two other formulae for the penicillin molecule received serious consideration. One was the tricyclic structure XIII and the other the azlactol structure XIV:



XIII



XIV

The tricyclic formula, suggested by Rohrmann of the Eli Lilly group (February 1944), and independently by F. A. Robinson of the Glaxo group (March 1944), contained the penillic acid skeleton preformed and could therefore explain the facile formation of the penillic acids in acid solution. It did not explain in a plausible manner the absence of a basic group in the penicillin molecule and the formation of α -esters and amides of the penicilloates under the influence of primary alcohols and amides. Esters of the penillic acids would be expected to be formed under these conditions. It was discarded when it was shown to be incompatible with the results of crystallographic X-ray measurements. The azlactol formula, suggested by Stodola of the Northern Regional Research Laboratory (September 1944), was a compromise between the β -lactam and the

thiazolidine-oxazolone structure. This formula also failed to explain the absence of a basic group in the penicillin molecule; furthermore, primary alcohols when reacting with the carbinol-amine group of the azlactol structure would be expected to give stable alkylethers.

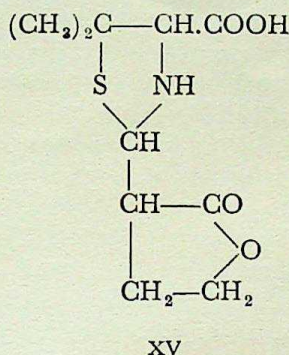
Measurements of the infra-red spectra of the penicillins were incompatible with both the tricyclic and azlactol structures.

DECISION BETWEEN THE β -LACTAM AND THIAZOLIDINE-OXAZOLONE STRUCTURES

I. EVIDENCE BASED ON THE STUDY OF MODEL COMPOUNDS

Numerous thiazolidines, with both free and acylated imino groups, were synthesized. All thiazolidines with free imino groups had pronounced basic properties, reacted instantaneously with iodine, were oxidized by permanganate to sulphonic acids, and poisoned hydrogenation catalysts. The thiazolidines with acylated imino groups had no basic group, were resistant to iodine, formed sulphones on oxidation with permanganate, and did not poison hydrogenation catalysts. The properties of the penicillins, which possess no basic group, do not react with iodine, form sulphones on oxidation of the methyl esters with permanganate, and can readily be reduced catalytically when possessing unsaturated side chains, are thus in accordance with those of an acylated thiazolidine such as is represented in the β -lactam structure, and are not compatible with a thiazolidine possessing a free imino group such as is postulated in the thiazolidine-oxazolone structure. At one stage of the investigations it was suggested that the carbonyl group in the

oxazolone ring and the imino group in the thiazolidine ring of the thiazolidine-oxazolone structure interacted in the same way as $>\text{NH}$ and $>\text{CO}$ in an amide group. It was found, however, that the basicity of the imino group in model compounds such as structure XV:

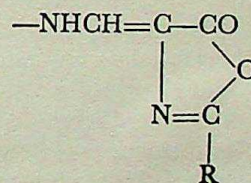


dines and oxazolones were all compatible with the β -lactam structure.

2. EVIDENCE BASED ON DEGRADATION STUDIES

(a) The Penicillenic Acids

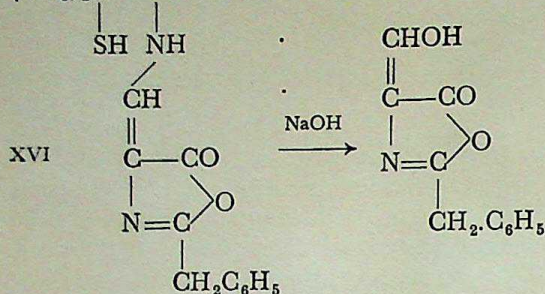
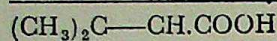
Thiazolidines are readily split by mercuric chloride into the thiol-amino and carbonyl components. The carbonyl component of the penicillin molecule, as represented by the thiazolidine-oxazolone structure, is a 2-substituted 4-hydroxymethylene-oxazolone. As soon as the thiazolidine-oxazolone structure was suggested attempts were made to isolate 2-benzyl-4-hydroxymethylene-oxazolone by decomposition of benzylpenicillin with mercuric chloride. They were unsuccessful. Penicillin proved to be much more stable towards mercuric chloride than ordinary thiazolidines with non-acylated imino groups; this was additional evidence against the thiazolidine-oxazolone structure. By the prolonged action of mercuric chloride benzylpenicillin was slowly decomposed into penicillamine, benzylpenilloaldehyde, and carbon dioxide. However, workers of the Merck group found that when the methyl ester of benzylpenicillin was treated with mercuric chloride in ethereal solution a product was obtained which exhibited a strong absorption band at about 3,200 Å. This band was shown to be characteristic of aminomethylene-oxazolones of the type:



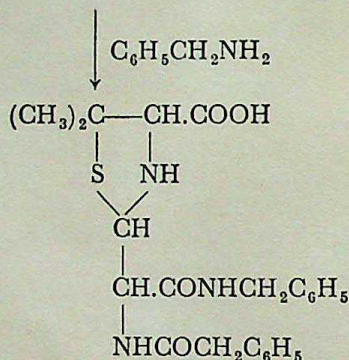
which had been prepared synthetically by condensation of hydroxymethylene-oxazolones and amines. The compound obtained from benzylpenicillin methyl ester by the action of mercuric chloride was termed penicillenic acid. With sodium hydroxide it was hydrolysed and the sodium salt of 2-benzyl-4-hydroxymethylene-oxazolone could be isolated in crystalline form. With benzylamine it reacted to give the benzylamide of benzylpenicilloic acid. On the basis of these reactions, which are represented in the following scheme, benzylpenicillenic acid was assigned the structure XVI. It could be synthesized readily by condensation of penicillamine and 2-benzyl-4-hydroxymethylene-oxazolone:

was not appreciably smaller than in other thiazolidines. Oxazolones of the type postulated in the thiazolidine-oxazolone structure were found to be much less stable in water than the penicillins. All oxazolones, even the most stable ones, react with liquid ammonia to give the amides of the corresponding acylated amino-acids; the sodium salts of penicillins were found to be stable in liquid ammonia. These results were not in agreement with the presence of an oxazolone ring in the penicillin molecule. A number of β -lactams were synthesized, among them some which contained the fused thiazolidine- β -lactam ring system postulated in the β -lactam structure. The β -lactams contained no basic group and in this respect resembled the penicillins; they differed from them in their greater stability towards acids, alkalis, alcohols, and amines. Perhaps the most significant data that emerged from the study of the β -lactams were the infra-red spectra of the fused thiazolidine- β -lactam models. They all showed bands close to 5.62μ , which are also exhibited by the penicillins. This band, which in simple β -lactams is shifted to values near 5.7μ , could be attributed to the carbonyl group of the β -lactam ring and was thus strong evidence for the presence of such a ring in the penicillin molecule.

Summing up the work on model compounds, it can be stated that it produced definite evidence against the thiazolidine-oxazolone structure, but, with the exception of the important infra-red data, no positive evidence for the β -lactam structure. However, the results of studies on thiazoli-



XVI

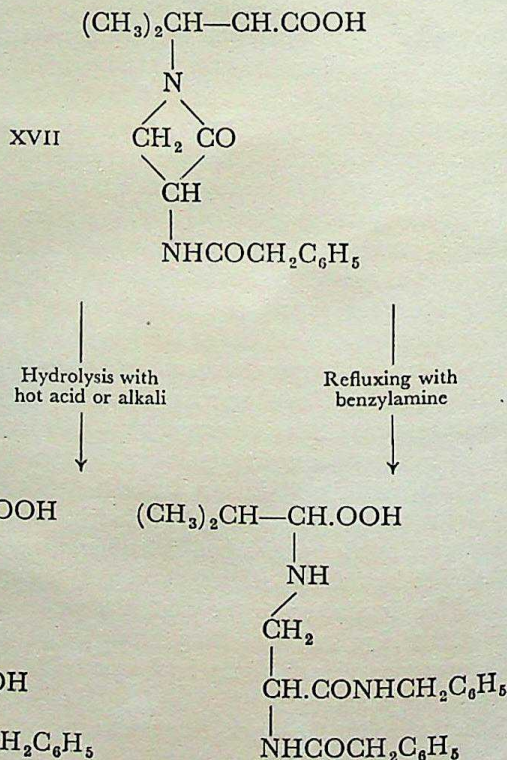


In the absence of other evidence, the isolation in crystalline form of one of the compounds of the thiazolidine-oxazolone structure would have had to be regarded as the strongest obtainable chemical evidence for this structure. However, at the time when the Merck workers isolated 2-benzyl-4-hydroxymethylene-oxazolone from benzylpenicillin methyl ester so much evidence against the thiazolidine-oxazolone structure had already been accumulated that a less simple explanation for its formation than the straightforward breakdown of this structure had to be taken into consideration, namely an intramolecular rearrangement of the β -lactam structure. That the penicillin molecule had the capability of readily undergoing intramolecular rearrangement was already known from the formation of the penillic acids in acid solution.

(b) Desthiopenicillin

The arguments in favour of the thiazolidine-oxazolone structure resulting from the isolation of 2-benzyl-4-hydroxymethylene-oxazolone were neutralized by the isolation of new degradation products on desulphurization of benzylpenicillin

with Raney nickel. This important work was carried out by members of the Merck group (December 1944 to April 1945). Three products were isolated. One had the composition $\text{C}_{16}\text{H}_{20}\text{O}_4\text{N}_2$ and was termed desthiobenzylpenicillin. It was a monobasic acid, not possessing a basic group and stable to refluxing with methanol and treatment with acid or alkali at room temperature. On warming with normal alcoholic hydrochloric acid at $60-75^\circ\text{C}$ for 15 minutes, or with 0.1N sodium hydroxide at 100°C for 15 hours, it was hydrolysed with the formation of desthiobenzylpenicilloic acid, a product which could also be prepared by desulphurization of benzylpenicilloates with Raney nickel. When refluxed for three hours in dioxane with benzylamine, desthiobenzylpenicillin was converted into the benzylamide of benzylpenicilloic acid by treatment with Raney nickel. On the basis of these reactions the only possible formula for desthiobenzylpenicillin was the β -lactam structure XVII, the alternative oxazolone structure being out of question because of the stability of the compound.

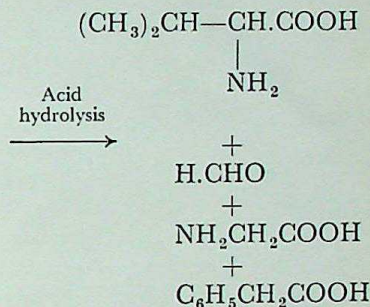
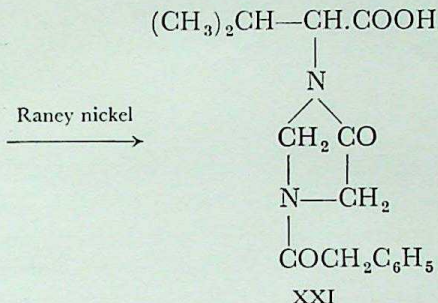
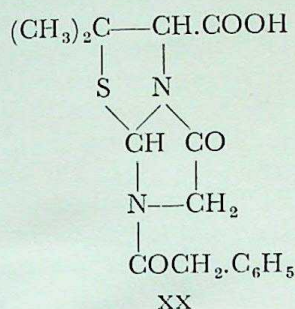


XVII

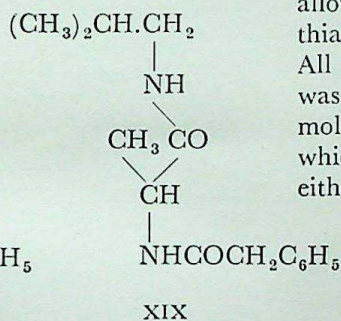
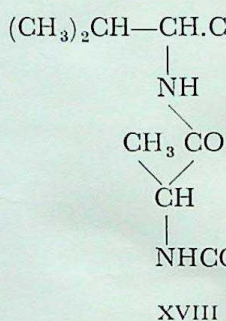
Thus two mild degradation reactions of benzylpenicillin had given products containing ring systems present in each of the two structures

under debate, and all that could be deduced with certainty was that the penicillin molecule had the capability of readily undergoing an intramolecular rearrangement in which either an oxazolone ring was transformed into a β -lactam ring, or a β -lactam ring into an oxazolone ring. The two other products of hydrogenolysis of benzylpenicillin with Raney nickel were identified as the isobutylamide of N-phenylacetyl-*l*(+)-alanine

This substance when subjected to hydrolysis with 20 per cent. hydrochloric acid at 100° C yielded phenylacetic acid, glycine, and valine. When heated at 120° C with 20 per cent. hydrochloric acid it gave one molecule of formaldehyde. On the basis of these reactions, represented in the scheme below, structure XXI was assigned to desthiobenzylpenillonic acid and the structure for benzylpenillonic acid was accordingly XX:



(XIX) and N-(N-phenylacetyl-*l*(+)-alanyl)-*d*(-)-valine (XVIII).



The formation of these products could be explained most easily on the basis of the β -lactam structure. In particular it was significant that product XVIII appeared to derive directly from benzylpenicillin, for it could not be obtained from desthiobenzylpenicillin by subjecting the latter to further hydrogenolysis.

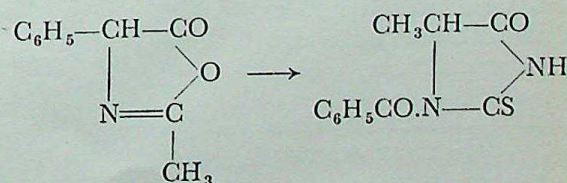
(c) Benzylpenillonic Acid

A new isomerization product of benzylpenicillin was isolated by the Merck workers (June-August 1944). It was formed when the methyl ester of benzylpenicillin was heated in boiling xylene, or in toluene in the presence of a trace of iodine. It was termed benzylpenillonic acid. The compound was stable to refluxing in xylene in the presence of benzylamine, and to cold acid or alkali. By treatment with Raney nickel it was transformed into desthiobenzylpenillonic acid.

The elucidation of the structure of penillonic acid did not contribute new factors which would allow a clear-cut decision to be made between the thiazolidine-oxazolone and β -lactam structures. All it showed was that the penicillin molecule was capable of undergoing yet another intramolecular rearrangement, the mechanism of which was difficult to explain on the basis of either structure.

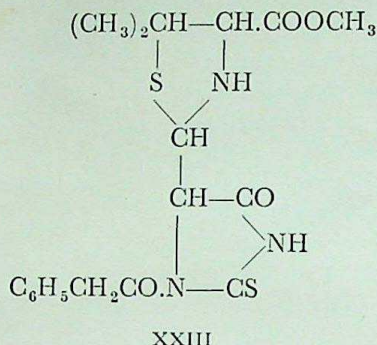
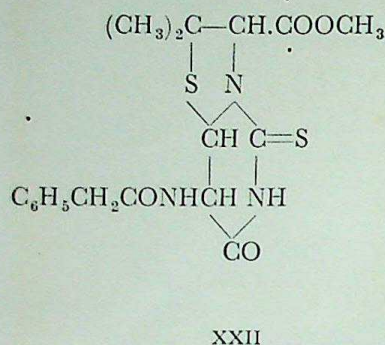
(d) The Thiocyanate Derivative of Benzylpenicillin

It was known that oxazolones reacted with thiocyanic acid to give 1-acyl-2-thiohydantoin. Thus 2-methyl-4-phenyl-oxazolone reacted with ammonium thiocyanate to give 1-benzoyl-2-thio-5-methylhydantoin:



Consequently the action of thiocyanic acid on benzylpenicillin was studied extensively (Cornell group and Squibb group, December 1944 to September 1945). A crystalline thiocyanate derivative was obtained by reacting the methyl ester of benzylpenicillin with ammonium thiocyanate. The elucidation of the structure of this compound showed, however, that it possessed the

dihydrothiouracil structure XXII and not the thiohydantoin structure XXIII:



It was synthesized by condensation of β -methyl *d*-benzylpenicilloate and potassium thiocyanate in the presence of acetic anhydride containing a trace of sulphuric acid. The formation of the thiocyanate derivative from benzylpenicillin could readily be explained on the basis of the β -lactam structure, whereas it was not easily understandable on the basis of the thiazolidine-oxazolone structure.

Summing up the evidence obtained from the degradation studies it can be stated that it was ambiguous with regard to the formation of penicillenic acid containing an oxazolone ring, and desthiopenicillin containing a β -lactam ring; the formation of the other products of hydrogenolysis, the *iso*-butylamide of *N*-phenylacetyl-alanine and *N*(*N*-phenylacetyl)-*l*(+)-alanine and *N*(*N*-phenylacetyl)-*d*(-)-valine, as well as the formation of the thiocyanate derivative, were in better agreement with the β -lactam than with the thiazolidine-oxazolone structure.

X-RAY CRYSTALLOGRAPHIC MEASUREMENTS

The final decision between the two structures, in favour of the β -lactam structure, was made through X-ray crystallographic studies. Fourier analyses of electron diffraction densities were made in three dimensions on single crystals of the sodium and potassium salts

of benzylpenicillin, and the interatomic distances between all atoms of the molecule were determined with an accuracy of 0.15 Å. They provided unambiguous evidence for the existence of the β -lactam ring in the penicillin molecule and definitely excluded the thiazolidine-oxazolone structure. In figure 1 a model of the molecule of benzylpenicillin based on the X-ray crystallographic measurements is represented. The molecule has a semicircular

form, the carboxyl group and the β -lactam ring lying on opposite sides of the thiazolidine ring while the amide side chain and the thiazolidine ring lie on the same side of the β -lactam ring. The α -carbon atoms of the penicillamine and penaldic acid moieties have different configurations, which is in accordance with the fact that penicillamine was shown by chemical degradation

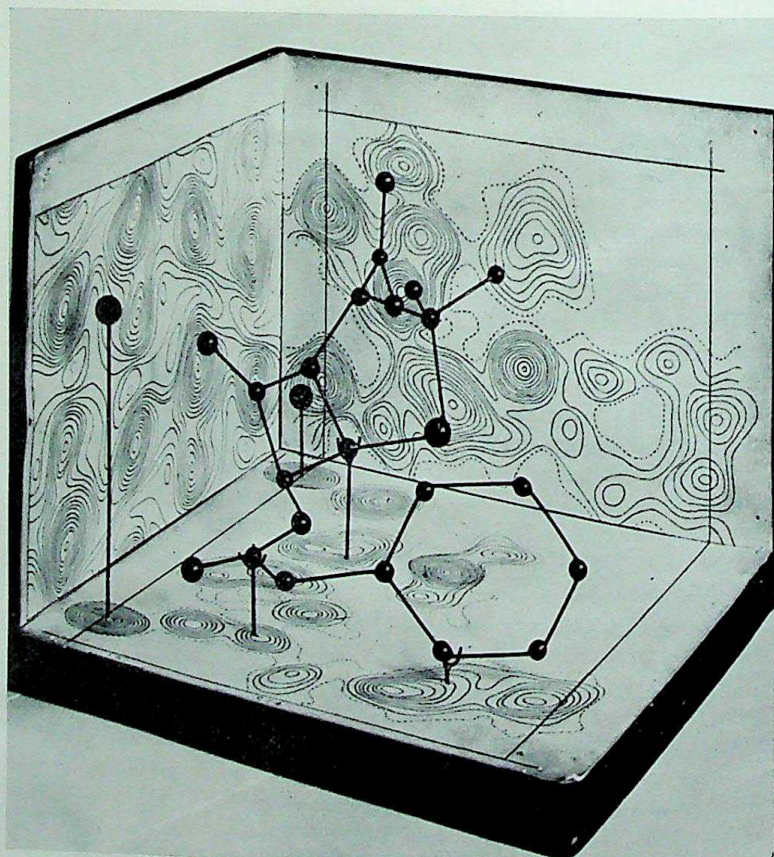
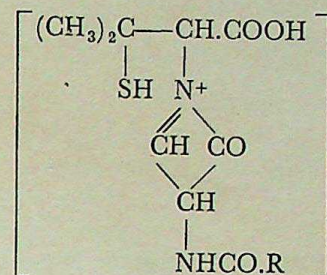


FIGURE 1 - Model of the molecule of benzylpenicillin.

to belong to the *d*-series and penaldic acid to the *l*-series.

Thus the X-ray crystallographic method has not only been of great value in the studies concerned with the structure of the breakdown products of the penicillins but has played an important role in the final elucidation of the structure of the penicillin molecule itself.

The unstable intermediate formed, possibly of the structure:



has the tendency to rearrange itself into an oxazolone. This is exemplified in the facile formation of benzylpenicillenic acid from the methyl ester of benzylpenicillin on treatment with mercuric chloride in ethereal solution. It is the amide side chain which makes possible and induces in the penicillin molecule the tendency to

undergo the rearrangement to an oxazolone. The further reactions of the intermediate oxazolones with alkalis, alcohols, or amines, leading to the opening of the oxazolone ring and the formation of penicilloates, follow as a matter of course.

Thus it is the tendency of the penicillin molecule to rearrange itself into a reactive oxazolone, after the primary fission of the thiazolidine ring, which is the cause of its high degree of reactivity, and it is clear why the model β -lactams which do not possess this tendency are much more stable. All the model β -lactams at present available, and desthiopenicillin, lack the combination of an amide side chain and a fused thiazolidine- β -lactam ring system, and it is on this combination of factors that the tendency of the penicillin molecule to rearrange itself into an oxazolone depends.

Another difficulty connected with the β -lactam structure was the penillic acid rearrangement occurring in acid solution. This reaction also presents no difficulties if the intermediate formation of an oxazolone is assumed. As was pointed out by Sir Robert Robinson at an early state of the investigations, the formation of penillic acid from penicillin on the basis of the thiazolidine-oxazolone structure was analogous to the formation of an amidine from an imino-ether, and an electronic mechanism for the rearrangement was suggested by him. It has now been shown that crystalline benzylpenicillenic acid can be transformed in good yield into benzylpenillic acid (du Vigneaud, communication to the Tenth

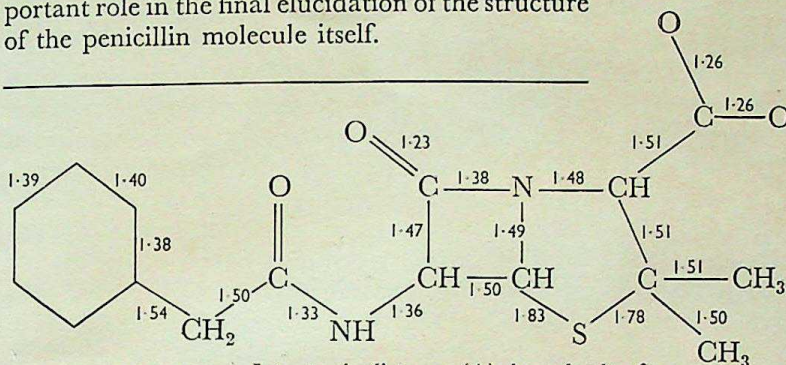


FIGURE 2 - Interatomic distances (Å) in molecule of benzylpenicillin.

EXPLANATION OF THE INSTABILITY OF THE PENICILLIN MOLECULE ON THE BASIS OF THE β -LACTAM STRUCTURE

The β -lactam structure having been established beyond doubt, an explanation for the reactivity of the penicillin molecule has to be found on the basis of this structure. One of the difficulties apparently inherent in the β -lactam structure is the fact that all hitherto-studied β -lactams, including desthiopenicillin and models containing the same fused thiazolidine- β -lactam system as is present in the penicillin molecule, proved to be very much more stable towards acid and alkali than the penicillins are. However, the penicillin molecule possesses structural features which are absent in the model compounds hitherto synthesized and in desthiopenicillin, and comparisons with these have therefore only a limited validity.

The reactivity of the penicillin molecule can be explained by assuming that it is not the β -lactam ring but the thiazolidine ring which is attacked and ruptured first under the influence of the different reagents. This is due to the tendency of the electronegative sulphur to give off electrons to cationic acceptors. This is almost certainly the case in the metal-catalysed alcoholysis of the penicillins which leads to the formation of penicilloates; the formation of penicilloates under the influence of alkalis or primary amines can be explained on the same basis.

International Chemical Congress, 1947), and thus it has been proved experimentally that the above-postulated type of conversion does in fact take place.

ATTEMPTS TO SYNTHESIZE THE PENICILLIN MOLECULE

Numerous attempts, which cannot be described in detail, were made to synthesize the penicillin molecule. These were predominantly directed towards the thiazolidine-oxazolone structure. Many attempts to ring-close penicilloates were made, but all proved unsuccessful; in no case was material possessing antibacterial activity of the penicillin type obtained. Another obvious method of synthesizing the thiazolidine-oxazolone structure was the condensation of penicillamine and 2-substituted 4-hydroxymethylene oxazolones. At an early stage of the work (early in 1944) traces of biologically active material were obtained by this method by workers of the Merck group and by the Oxford workers. Later it was shown that the antibacterial material obtained by condensation of *d*-penicillamine and 2-benzyl-4-methoxymethylene-oxazolone in pyridine at 75° C behaved biologically and chemically like benzylpenicillin. Finally a small amount of the crystalline triethylamine salt was isolated from the reaction mixture, and this proved identical with the natural compound. It has not been possible to increase the yield of the active material. Methods designed to give specifically the β -lactam structure have not so far led to the formation of biologically active material of the penicillin type.

Thus the paradoxical situation has arisen that the only method of preparation which has given a trace of synthetic penicillin was devised on the basis of a structural formula for the penicillin molecule which has since been proved incorrect.

SEMI-ARTIFICIAL PENICILLINS

The only natural penicillin that can be chemically modified by the introduction of different groups into its side chain is *p*-hydroxybenzylpenicillin. *p*-Hydroxybenzylpenicillin can be diazotized in aqueous solution, under conditions in which the biological activity is preserved (Northern Regional Research Laboratory, 1944), and numerous 'azopenicillins' have been prepared by coupling it with various diazonium salts. This method allows of the introduction of a great variety of groups into the penicillin molecule. The azopenicillins are active against the same bacteria as the natural penicillins, and their antibacterial activities are of the same order, though small quantitative differences exist. Their pharmacological properties have not yet been studied. *p*-Hydroxybenzylpenicillin can also be iodinated, and 3:5-di-iodo-4-hydroxybenzylpenicillin was isolated in the form of its crystalline sodium salt. Semi-artificial penicillins can also be prepared by the addition of chemical precursors during fermentation. The production of benzylpenicillin is increased when phenylacetic acid or phenylacetamide is added to the culture medium, and it was shown that ring-substituted phenylacetic acid derivatives are also incorporated by the mould into the penicillin molecule (Eli Lilly group, 1944). In this way a number of penicillins containing substituted benzyl groups in their side chains, such as *p*-methoxybenzyl-, *p*-fluorobenzyl-, and others, have been prepared in the form of their crystalline sodium salts.

The chemical work on penicillin has brought to light a multitude of new facts which may have importance beyond the limited field of penicillin chemistry.

REFERENCES

- [1] FLEMING, A. 'On the Antibacterial Action of Cultures of a *Penicillium*, with Special Reference to their Use in the Isolation of *B. influenzae*,' *Brit. J. Exp. Path.*, 10, 226, 1929.
- [2] CLUTTERBUCK, P. W., LOVELL, R., and RAISTRICK, H. 'Studies in the Biochemistry of Microorganisms. XXVI: The Formation from Glucose by Members of the *Penicillium chrysogenum* Series of a Pigment, an Alkali-soluble Protein, and Penicillin—the Antibacterial Substance of Fleming,' *Biochem. J.*, 26, 1907, 1932.
- [3] CHAIN, E., FLOREY, H. W., GARDNER, A. D., HEATLEY, N. G., JENNINGS, M. A., ORR- EWING, J., and SANDERS, A. G. 'Penicillin as a Chemotherapeutic Agent,' *Lancet*, ii, 226, 1940.
- [4] ABRAHAM, E. P., CHAIN, E., FLETCHER, C. M., FLOREY, H. W., GARDNER, A. D., HEATLEY, N. G., and JENNINGS, M. A. 'Further Observations on Penicillin,' *Lancet*, ii, 177, 1941.
- [5] ABRAHAM, E. P., BAKER, W., CHAIN, E., and ROBINSON, R. 'Penicillamine, a Characteristic Degradation Product of Penicillin,' *Nature*, 151, 107, 1943.
- [6] CHAIN, E., and FLOREY, H. W. 'Penicillin,' *Endeavour*, 3, 3, 1944; 'The Discovery of the Chemotherapeutic Properties of Penicillin,' *British Medical Bulletin*, 2, 5, 1944.
- [7] CHAIN, E. 'The Chemistry of the Penicillins,' *Ann. Rev. Biochem.* (in press).
- [8] CHAIN, E., and PHILPOT, F. J. 'The Catalytic Effect of Metal Ions on the Alcoholysis of the Penicillins,' *Arch. Biochem.* (in press).

DAVID S. EVANS

Solar prominences provide astronomers and astrophysicists with many difficult problems. In recent years new methods of observation of the prominences have been elaborated, including the ingenious device of producing an artificial solar eclipse employed by Professor Lyot at the Pic du Midi observatory. Dr Evans describes modern work on the subject and himself suggests a possible explanation of the way in which the prominences are supported.

At times of total eclipse it may be seen that the sun possesses a number of appendages: the corona, of a pearly white colour, and of a total brightness about equal to that of the full moon, which extends outwards from the sun for something of the order of one and a half million kilometres, the radial distribution being roughly uniform but diversified at times by narrow streamers issuing from the poles of the sun or by other structural details. At such times there may also be seen solar prominences—flame-like, luminous, red-coloured structures issuing from the hidden disk of the sun and extending outwards for a distance of perhaps one hundred and fifty thousand kilometres or more. In addition, instrumental methods of observation disclose the existence of a solar surface layer, the chromosphere, a few thousand kilometres in thickness, the light of which originates not in general heat radiation as does that from the solar disk, but in spectral lines of elements in emission.

These solar appendages are rendered visible by the cutting off of the overpowering light from the solar disk by the interposition of the moon, but since this is a very rare occurrence methods have been developed for the continuous observation of the appendages at all times. Historically the first of these was the method of the spectroheliograph, an instrument which represents an extension of the principle of the spectroscope. A spectrum of a part of the solar surface is formed by placing a slit across an image of the sun formed by a telescope. From this spectrum one line is selected by means of a second slit, so that what is transmitted by the second slit is an image of part of the solar surface in light of a single colour. By scanning the solar image through the first slit, keeping the wavelength selected by the second the same, it is possible to build up, strip by strip, a monochromatic image of the sun. The principle was developed in this form by the American

astronomer Hale, and independently, and with differences of detail, in the form of an instrument known as the *enregistreur des vitesses* by the French astronomer Deslandres, both in 1890. If the selected wavelength is that of a strong absorption line on the solar disk the brightness of the disk is much reduced, and if it is also a wavelength in which the prominences emit strongly (e.g. one of the Balmer lines of hydrogen) the brightness of the prominences relative to the disk will be much increased and will appear on the resulting spectroheliogram. A further development of this method has been made by McMath and his colleagues [1], who devised the spectroheliocinematograph, in which a scan of part of the solar disk is made very rapidly and recorded on a frame of ciné film. When projected, the film shows movements and changes of form in prominences in the most striking way.

The function of the spectroheliograph is thus that of a filter. An alternative method of observation developed by Lyot is that of the construction of an artificial solar eclipse [2]. Tremendous technical difficulties had to be overcome, but the principle is very simple: an image of the sun and surrounding sky is formed, and the solar image is blocked out by a disk. Additional lenses remove light scattered by the periphery of the first lens, and in the final image the prominences can be seen standing out from behind the disk covering the sun. The attainment of this result required many years of work and equipment of the highest quality, but already several years before the war Lyot had succeeded in obtaining ciné films of prominence movements at the observatory of the Pic du Midi at an altitude of almost 3,500 metres in the Pyrenees. A newly established station of the Harvard Observatory at Climax, Colorado, has succeeded in duplicating Lyot's equipment.

Lyot himself has recently given an account of a completely different observational technique [3]

which permits observations not only of the prominences and of the inner corona, as did his first instrument, but also of the solar disk, the chromosphere, and a much greater extent of the corona. The device is an optical analogue of the band-pass filter, and consists of a series of plates of quartz of thicknesses 1, 2, 4, 8, etc., units. These plates form a stack through which the light passes from end to end. The optical axes of the quartz plates are parallel and in the plane of their faces. Before and after the first and last plates and between each pair are placed polarizers (e.g. Polaroid sheets) with axes at 45° to the quartz axes. This arrangement gives a filter transmitting a certain fundamental wavelength, which depends on the thickness of the first quartz plate, and all integral multiples of that wavelength. The transmitted wavelengths can be varied by changing the temperature of the filter by a few degrees. The width of the band passed at each wavelength depends on the number of quartz plates used. By the use of this device modified in certain details, notably by the use of birefringent polarizers which can be used to produce a number of separated images, Lyot has been able to produce simultaneous trichromatic ciné films, showing the solar surface, the prominences, and the corona as seen in the light of the green coronal line at 5303 Å, the red coronal line at 6375 Å, and the H α line of the prominences at 6563 Å.

In a sense the original Lyot method and the McMath method were complementary. McMath's method showed not only the prominences but the solar disk beneath them, though it suffered from the disadvantage that line-of-sight motions of prominence material might cause a Doppler shift of the emitted wavelength sufficient to displace its image off the second slit. This would mean that a portion of a prominence in rapid recession would not be recorded, and parts of prominences might seem to vanish or appear simply as a result of change of line-of-sight velocity.

More recently an instrument of a new type has been installed at the McMath Hulbert Observatory which enables true three-dimensional movements of prominence material to be determined [4]. On each frame of the cinematograph film a scan of the prominence is first made with a wide slit of sufficient breadth to include even large shifts due to Doppler effect. The resulting strips thus each show at their centres an emission line due to the prominence, which will be distorted at places where line-of-sight motions are taking place. From the amounts of these distortions the

line-of-sight motions can be determined. In order to fix the parts of the prominence to which these radial motions refer and to determine transverse motions, a continuous scan, slightly underexposed, is made on the same frame of the film. This method thus eliminates one of the disadvantages to which the original spectroheliocinematograph observations were subject.

The particular disadvantage from which Lyot's original observations suffered was that, owing to the necessity of making the obscuring disk slightly larger than the apparent size of the sun, neither the solar surface beneath the prominences nor certain types of prominence (particularly the surge prominences—short spikes ejected from the sun and almost immediately retracted) could be observed. Such prominences could be observed on the McMath films. On the other hand, Lyot's films had a greatly superior definition and did not suffer from possible distortion by Doppler effects. Even now, however, with Lyot's new methods and the elimination of the obscuring disk, it seems probable that the work of the two observatories will remain complementary in many respects.

It will already be clear by implication that prominences show a great variety of form, but certain generalizations about all types are possible. In particular, prominences are usually associated with sunspots or disturbed regions of the solar surface, and spectroheliograms of sunspot regions often show curved filamentous structures which, when carried to the limb by solar rotation, prove to have been prominences seen from above.

Among the smaller types of prominence which are observed, in addition to the surge prominences already mentioned, are those known as tornado prominences, which resemble a gaseous waterspout, showing a luminous column perhaps 100,000 km in height which has a rapid rotational motion but only a relatively small bodily translation. The largest prominences may be up to several hundred thousand kilometres in height, with a basal extension sometimes several times as large. Some consist merely of quiescent columns of gas, but explosive types also occur, and in some cases the velocity of ejection of material from the solar surface may be so great that a mass of material is thrown out and becomes permanently detached.

It is necessary, however, to emphasize the curious observational fact that the vast majority of prominence motions are downwards and not upwards, and that the flame-like appearance is deceptive and likely to lead to conclusions that are false if pressed too far. Just before the war the

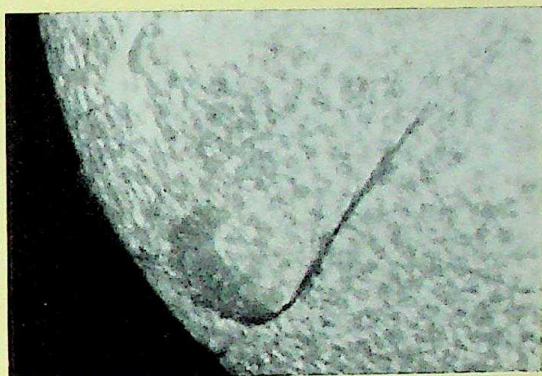
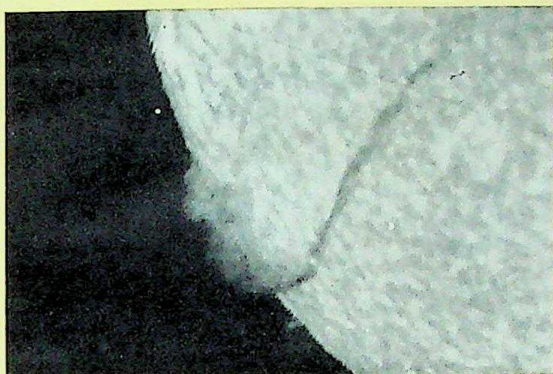
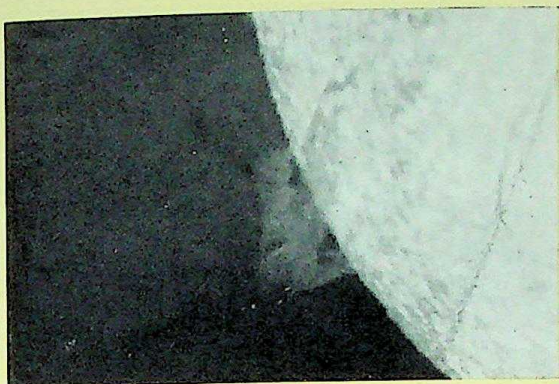


FIGURE 1 - *Solar prominence. Meudon Observatory. 26th, 27th, 28th, and 29th August, 1929.*

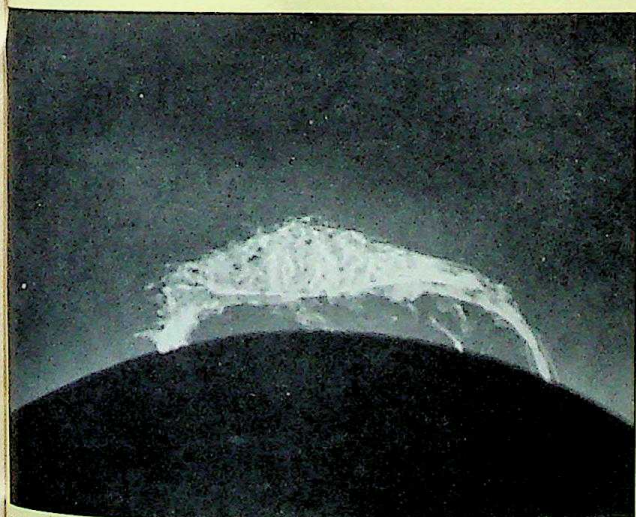
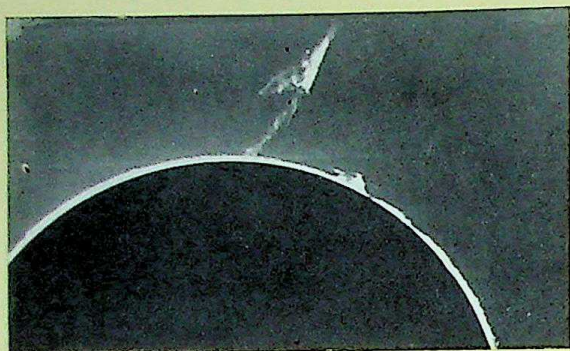


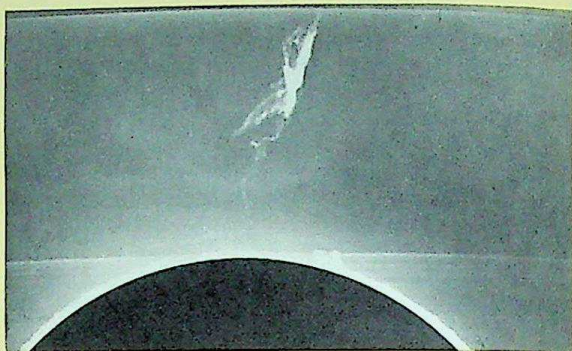
FIGURE 2 - *Great prominence. Total eclipse of sun, 29th May, 1919. Taken at Sobral (Brazil).*
(Reproduced by permission of the Astronomer Royal.)



FIGURE 3 - *Solar prominences, 10th October, 1910. Yerkes Observatory. Upper photograph taken at 7.57 and lower at 8.06 G.M.*



7 h. 52 m.



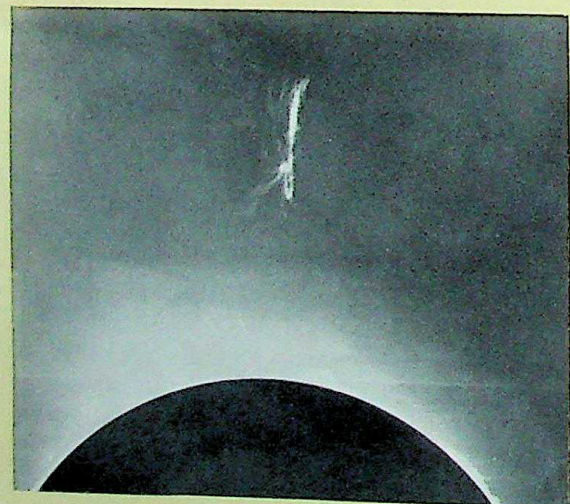
8 h. 35 m.



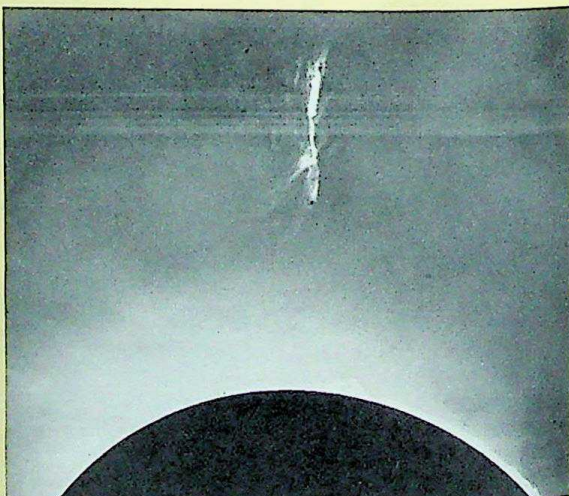
8 h. 45 m.



8 h. 52 m.



8 h. 58 m.



9 h. 3 m.

FIGURE 4 - Eruptive prominence (max. height 567,000 miles). Photographs by Royds. Kodaikanal. 19th November, 1928.

films of McMath and of Lyot were shown in London and aroused intense interest. The delicacy of appearance (particularly of Lyot's pictures), the complexity of movement, and infinite changes of form and structure aroused audiences to enthusiasm. The particularly striking features were the very narrow streamers issuing from prominences, along which matter passed downwards either in continuous motion, or in the form of knots which had the appearance of moving along, as it were, predestined paths. It became a problem for heated discussion whether these motions were real motions of matter, as they seemed to be from the appearance of moving knots, or whether they consisted in the propagation of a state of excitation through stationary material, as the appearance of fixity of the paths might suggest.

In this connection certain observations of Pettit [5], the veteran American prominence observer, are of importance. Working with material from the McMath Hulbert Observatory and earlier data, he had arrived at a series of laws for the motion of prominence knots. He considered that the motions were at constant speeds for considerable intervals, and that when a velocity change did occur it was instantaneous, the amount of the change being a simple multiple of the original speed of the knot. Doubt was cast on this 'quasi-quantum' set of laws by Hulme [6], who showed that, provided there was a prejudice in favour of this type of law, then a formula of this kind could be fitted to a perfectly smooth time/distance curve as modified by random observational error.

The attention of Zanstra [7] was particularly caught by the appearance of the narrow streams. He conducted a number of hydrodynamical experiments in which he found that water flowing into a shallow dish, under a head of a few millimetres, through a hole in the base assumed a flow pattern which broke up into a number of very narrow streams. He was able to show that under certain viscosity conditions this was a characteristic of flow against the pressure gradient, and he proposed a model in which prominence luminosity was to be accounted for by the collapse of a cloud of gas towards the solar surface (the potential energy being converted into excitation energy) and in which the flow, according to his theory, should break into narrow streams.

An electromagnetic theory of certain prominence forms was proposed by Alfvén [8], but his explanation was not very inclusive and the forms explained were not the most striking of those observed. At a later date Bruce [9] proposed a

somewhat general theory, in which a possible analogy between prominence forms and the phenomena of terrestrial lightning was drawn.

The observed forms and motions of prominences pose immediately a number of problems. There is a superficial analogy with flames or with terrestrial clouds, but both of these are merely visible parts of a larger invisible atmosphere. In the solar case, have we to deal with isolated luminous masses, and in that case, how are they supported, or have we to deal with a much more extensive atmosphere, of which only part is luminous? This too merely raises a host of new problems. On the observational side, the work of Thackeray [10] and of Brück and Moss [11] shows that hydrogen and helium are well mixed in prominences, while, on the theoretical side, ten Bruggencate [12] has advanced reasons for the belief that prominence support cannot be due to selective radiation pressure, a conclusion which seems to rule out all the obvious support mechanisms.

It has recently been suggested by Evans [13] that many of these properties are explicable on the assumption that the observed motions are those of ions in a magnetic field. Ions are certainly present in prominences, and magnetic fields in the sunspots with which they are associated. The thin streamers would then be the characteristic paths of different ions.

Electromagnetic forces alone produce no change of speed, since they always act at right angles to the direction of motion, but if many ions are present these forces will be supplemented by those of electrostatic repulsion. Investigation of the dispersal of ion clouds under their internal electrostatic repulsion shows that the measures of true 'three-dimensional' motions of prominence knots made by McMath and his colleagues [14] can be fitted by velocity curves computed either for the general dispersion of ion clouds or for ions projected through such dispersing clouds. It is found that a charge density of 10^{-11} to 10^{-12} elementary charges per ml is sufficient to produce agreement with observation. The work suggests a picture in which the observed prominence represents a series of regions of enhanced density or excitation in a somewhat more extensive tenuous ion cloud.

As we have seen, traditional support mechanisms for prominences seem to be excluded. Some years ago Dyson and Woolley [15] drew attention to the possible importance of electrostatic effects in connection with chromospheric phenomena, and it seems possible that the mechanism of prominence support must be sought along these

lines. In stellar interiors, as Pannekoek [16] and Rosseland [17] showed, dissociated material is polarized by the tendency of the electrons to separate from the heavier ions by diffusion under gravity, but ideally this field should cease at the solar surface, where a layer of electrons should give a sun which is electrically neutral. However, there is an additional effect, namely the preferential escape of electrons discussed by Milne [18], which should, as it were, cause an extension of this field up to the top of the cloud of escaped electrons, which may be tentatively identified with the corona. It is practically impossible at the present time to estimate this field intensity on theoretical grounds, but if it is of the same order as the internal Pannekoek-Rosseland field it should be of roughly the magnitude necessary for the complete support of hydrogen ions against gravity, or possibly even higher. Ions are produced most copiously in the regions of abnormally high excitation associated with sunspots, and, assuming a field of the order mentioned, it is possible to compute the maximum diameter of a spherical aggregation of ions of the charge density deduced for prominences. This diameter is reached when the local field produced by the cloud balances the general field and prevents the further escape of ions. It turns out to be of the order of a few hundred thousand kilometres, i.e. roughly of the order of size of the largest prominences. It is also interesting that if a field of this order is assumed, then the highly stripped ions identified in the corona by Edlén [19] will also derive roughly complete support against gravity from it. Since the field, if it exists, will decrease with height as more coronal electrons are left below, we should expect that for ions of a given mass the height attained should increase with the charge. Eclipse observations by Allen [20] seem to suggest an effect of this kind.

If the controlling magnetic field is assumed to be a dipole, a great variety of paths of charged

particles is possible, depending on the circumstances of projection. One family, corresponding to projection in the median plane of the dipole, is such that motion always remains in this plane, and the family splits into two groups. One group consists of paths which extend spiralwise to infinity; the other consists of small, virtually closed paths. It is possible to identify the streamer forms observed in certain types of prominence with paths belonging to the first group, and in detailed analysis of two prominences it was found possible, ignoring possible foreshortening effects, to bring all the observed tracks into accord with the hypothesis of motion under the influence of a dipole located in the solar surface below the prominence. A minimum value for the dipole moment could be estimated, and, although possibly rather small, it was of the right order of magnitude for a sunspot field.

A peculiarity of the second group of orbits, which, as we have noted, are virtually closed, is that for given circumstances of projection, ions having more than a certain number of charges can be retained in orbits of this group, while those of lower charge pursue paths of the type of the first group and escape to infinity. The possibility therefore arises of the occurrence of very small prominences of abnormally high excitation. These have been identified with the tornado prominences already described, the controlling dipole now being supposed to be normal to the solar surface. A more detailed discussion also accounts for the inclined plume of gas above the vertical column which is often observed in tornado prominences. It is moreover possible in this case to estimate the moment of the postulated dipole, and results in general accord with the observed sunspot fields are found. Other types of possible orbit can be matched against other observed forms of prominence, but the possibilities of detailed analysis are more limited.

REFERENCES

- [1] McMATH and PETRIE. *Pub. Obs. Univ. Michigan*, 5, 103, 1934.
- [2] See e.g. *Month. Not. Roy. Astr. Soc.*, 99, 580, 1939.
- [3] *Ann. d'Astrophysique*, 7, 31, 1944.
- [4] McMATH. *Pub. Obs. Univ. Michigan*, 8, 141, 1941.
- [5] *Astrophys. J.*, 50, 206, 1919; 76, 9, 1932; 84, 319, 1936.
- [6] *Month. Not. Roy. Astr. Soc.*, 99, 634, 1939.
- [7] *Ibid.*, 99, 499, 1939.
- [8] *Arkiv. f. Math., Ast., och Fys.*, 27 A, 3, 1941.
- [9] 'The Observatory,' 66, 262, 1946.
- [10] *Ibid.*, 64, 169, 1941.
- [11] *Month. Not. Roy. Astr. Soc.*, 103, 258, 1943; 105, 17, 1945; 105, 282, 1945.
- [12] *Veröff. Univ. Sternw. Göttingen*, No. 77, 1944.
- [13] *Month. Not. Roy. Astr. Soc.*, 106, 300, 1947.
- [14] McMATH, SAWYER, and MOHLER. *Pub. Obs. Univ. Michigan*, 8, 123, 1941.
- [15] *Eclipses of the Sun and Moon*, p. 101 (O.U.P., 1937).
- [16] *Bull. Astron. Inst. Netherlands*, 1, 107, 1922.
- [17] *Month. Not. Roy. Astr. Soc.*, 84, 720, 1924; 85, 541, 1925.
- [18] *Trans. Camb. Phil. Soc.*, 22, 83, 1923.
- [19] See e.g. *Month. Not. Roy. Astr. Soc.*, 105, 323, 1945.
- [20] ALLEN. *Ibid.*, 106, 137, 1946.

Grafting of animal tissues

G. M. WYBURN and P. BACSICH

The grafting of plants has been practised in agriculture for centuries and can sometimes be effected even between species of different genera. In animals, however, and especially in mammals, it is often difficult to graft tissue even from one part of the body to another part of the same animal. The practical importance of this method for repairing severe injuries, much more numerous in recent years through war and mechanization, has led to great attention being paid to the grafting of animal tissues and the conditions necessary for success.

The grafting of plants is a well-known procedure. The operation consists in the union of scion (graft) with the stock (root system) of another plant, e.g. grafting a cultivated rose on to a briar, or a Cox's orange pippin on to a crab-apple. The composite individual is a form of plant chimera. The principal, and possibly the only, way in which the stock affects the scion is directly through nutrition, and scion and stock preserve their morphological and physiological independence. The closer the systematic relationship of scion and graft, the more likely is successful union of their tissues. However, grafts between plants of different genera sometimes succeed, e.g. lilac on to privet or tomato on to potato. When the relationship is more distant than generic there is protoplasmic incompatibility, and graft union cannot be brought about. In these horticultural expedients the degree of differentiation and specialization of the plant tissues concerned does not seem to influence the result.

With animal tissues, on the other hand, the more complex the organism the more improbable is a successful graft from one animal to another. In simpler organisms, such as *Hydra*, the graft can be of different species (heterograft), and animal chimeras are formed in which the graft and host retain the characteristics of their own species.

Phylogenetic advance confers benefits but also imposes penalties, one of which is the inability of the tissues or organs to adapt themselves to a new environment and survive within the body of another individual. The complex anatomy of higher animals is the structural expression of a physiological division of labour. Groups of cells take on different functions and structurally adapt themselves to perform their allotted task. This differentiation, however, connotes a loss of plasticity, so that in mammals not only are heterografts impossible, but a graft from one animal to another of the same species (homografts) does not survive (with one or two exceptions). The only

consistently successful form of tissue transplantation in mammals is the autograft, i.e. a graft of tissue from one region of an animal to another region of the same animal. The tissues are now not only species specific but individually specific. The corollary of specialization is specificity.

This rigid specificity is a characteristic of the adult animal. In the embryo or larva the tissues for a time remain undetermined. Their fate has not yet been settled, and they are potentially capable of specializing in any one of several directions. Embryonic plasticity extends to transplantation, and much knowledge has been gained about the processes of development by grafting experiments on embryos and larvae. The control centre of the embryo is the 'organizer,' which directs the pattern of events and determines the development of each part of the embryo. If the organizer region of one embryo is transplanted into another embryo of approximately similar age, there is no coalition or co-operation with the host organizer. Both work independently, and effort is made to fashion two individuals from substance intended for one. Larval chimeras can be formed by grafting together different parts of different embryos, e.g. the anterior half of *Rana palustris* to the posterior half of *Rana virescens* (figure 1). This composite organism behaves physiologically as one unit and undergoes metamorphosis into an adult frog, but the two components retain some of their specific characters, particularly as regards pigmentation.

Other grafting experiments have shown that once a part of the embryo has been determined by the organizer, it will pursue its determined destiny even after transplantation into new surroundings. For example, a presumptive limb, i.e. the part of an embryo which has been determined to form a limb, if grafted elsewhere not only preserves its identity but differentiates in the appointed direction and forms a limb. The developmental forces inherent in the donor embryo have

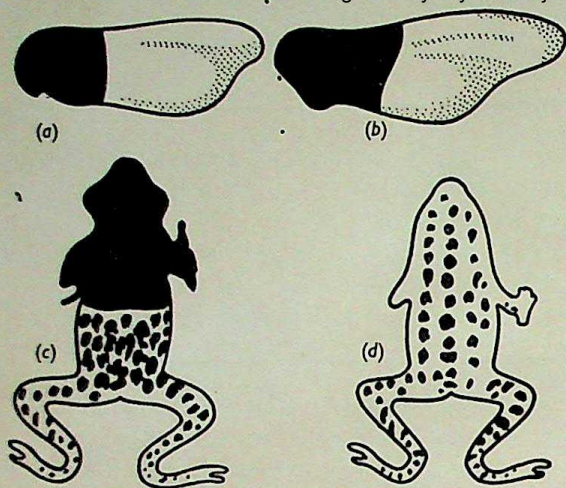


FIGURE 1 - Embryonic chimera produced by grafting together anterior half of *Rana palustris* and posterior half of *Rana virescens*. (a) Shortly after operation. (b) Later stage. (Note differential growth of anterior component.) (c) Adult frog with pigmentation of *Rana palustris* in front and pigmentation of *Rana virescens* behind. (d) Normal *Rana virescens*.

[Adapted from Wells (Huxley and Wells, The Science of Life, London, 1929).]

stamped immutable individuation on the graft.

Following the discovery that organs such as the thyroid, pituitary, and sex glands elaborated secretions or hormones with far-reaching effects on function and structure, efforts were made to treat conditions due to hormonal deficiencies by grafting the appropriate endocrine gland in the hope that it would survive and function actively. Indeed, the first scientific confirmation of a testicular hormone responsible for the external manifestations of 'maleness' was the result of the grafting experiments of Berthold in 1849. Berthold castrated six cockerels, but in some of them he replaced the testicle elsewhere. Those with the autograft gland developed into typical cocks with the usual physical characteristics and behaviour. The others grew into typical capons—fat, docile, devoid of combs, wattles, spurs, and vocal exuberance.

If an endocrine gland is not secreting sufficient of the necessary hormone, it is obviously unsuitable as an autograft, and therefore attempts have been made in mammals to transplant glands from another individual (homografts). Although from time to time there are reports of the successful 'taking' of a homograft hormonal gland, it is generally agreed that the ultimate decease of the graft is inevitable. The homograft may acquire a blood-supply and survive and function for some weeks. The length of the survival period is influenced by the genetic relationship of host and

donor. In transplantation experiments with closely inbred strains of mice, the glandular homografts may live for long periods, especially if the host is deficient in the hormone secreted by the graft, or if this particular gland had previously been removed from the animal. The needs of the host thus help to determine within limits the fate of the donor gland. Obviously, in dealing with human beings, even if there were any prospect of success, it is not practicable to remove a vitally necessary gland from one individual for implantation into another. The now notorious 'monkey-gland' operation of Voronoff illustrates the result of grafting glands from one species of animal to another (heterograft). From 1912 to 1925 Voronoff implanted monkey testes into human beings. Despite a temporary euphoria of doubtful origin, the elderly patients did not become rejuvenated. It can be stated categorically that grafting from one animal to another to replace functionally defective organs is a failure as far as mammals, and particularly man, are concerned.

At present, grafting is confined to the repair and replacement of tissue defects and gaps. Thus skin graft replaces skin lost from injuries, such as burns. Bone grafts also are a commonplace, and armed with bone and skin the plastic surgeon may reconstruct a finger or a nose. Both skin and bone are autografts taken from some other part of the patient. Blood-vessels and nerves grow into the graft, which becomes incorporated into the vascular and sensory pattern of the region. The graft, however, may retain, and sometimes rather embarrassingly evince, its individuality. For instance, skin grafts from a hairy region will grow hairs in a hairless recipient area, or the skin pigment (melanin) may become aggressive and darken the grafted skin. It would, of course, greatly extend the possibilities of grafting operations if homografts could be used. Recently, intensive studies have been made of skin homografts in animals and man. It was found that many of the grafts 'took,' were vascularized, and appeared to settle down in their new surroundings. After a period of about three weeks, however, the grafts became necrotic and sloughed off. It is suggested that the homograft, like foreign protein, acts as an antigen and stimulates the formation of antibodies within the host, which now acquires an active immunity against the graft. The cells of the host then invade and destroy the graft. The severity and strength of the host attack are directly proportionate to the genetic difference between host and donor tissues. A heterograft excites a

FIGURE 2 - High-power view of part of a cartilaginous homograft from a guinea-pig. A part of the rib of an adult animal was inserted subcutaneously in the host and removed twenty-one days after insertion for histological examination. There is only a moderate host reaction present, and the graft retained its normal histological characteristics. The cartilaginous ground-substance gives the typical metachromatic staining reaction after the application of certain specific dyes. In fact, it can be compared favourably with normal cartilage.

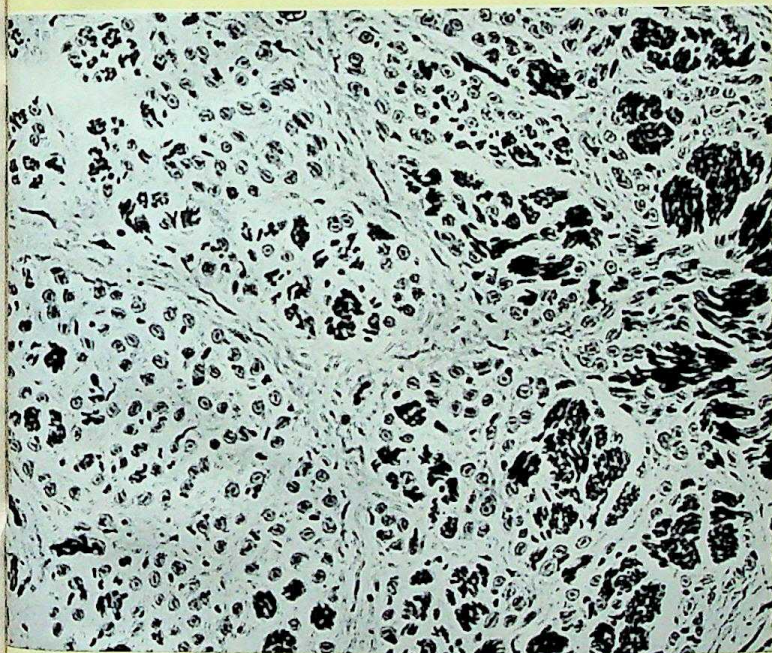
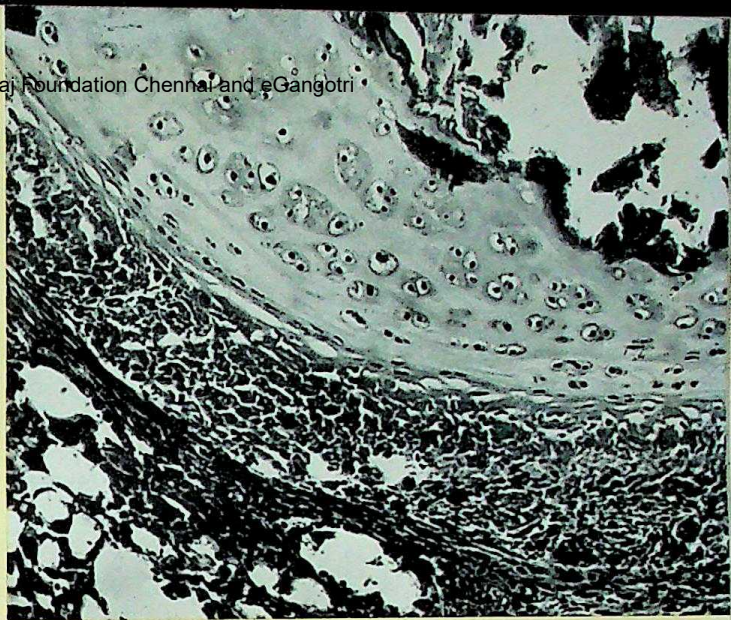


FIGURE 3 - High-power view (cross-section) of a nerve bundle from a normal human peripheral nerve. Connective tissue bands inside the nerve bundle divide the nerve fibres into gradually smaller and smaller sub-groups, and ultimately each individual nerve fibre is completely isolated from its neighbours by a connective tissue sheath. In the middle and the left-hand side of the picture the majority of the nerve fibres appear as small circles with a small dot in the centre. These are the myelinated fibres, which are provided with a myelin sheath and a cellular sheath. These fibres carry the highly differentiated impulses and consequently are better insulated. In the right-hand side of the picture the majority of nerve fibres appear as small dark dots owing to their more twisted course, as small spirals. These are non-myelinated nerve fibres and are provided with a cellular sheath only. They carry less highly differentiated impulses and consequently are less efficiently insulated.

FIGURE 4 - High-power view (cross-section) of a small nerve bundle from a regenerating human nerve autograft. The grafting operation was carried out two years after the injury, by which time there was considerable fibrosis present. Nevertheless the nerve fibres traversed the whole length of the graft. Apart from the main nerve bundle in the picture closely populated by regenerated nerve fibres, there are also present small groups of aberrant nerve fibres.

In nerve-regeneration all regenerating fibres are at first non-myelinated. Myelination and the return of function occur later. As there were no signs of recovery of function nearly six months after the operation, the graft was removed for histological examination. None of the nerve fibres is myelinated, probably because of the fibrosis. This case demonstrates the capacity of the central stump for regeneration after a long interval of time.

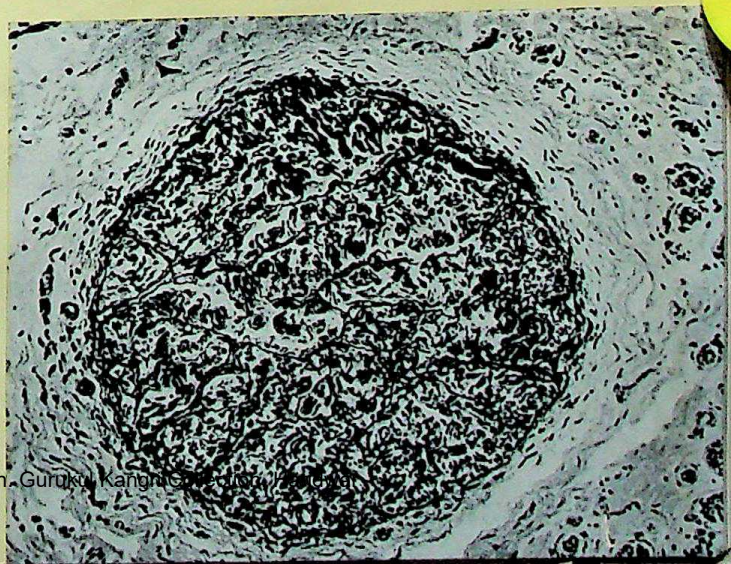




FIGURE 5 - Low-power view (cross-section) of a human nerve homograft. The connective-tissue ground-substance appears to be reasonably normal, though somewhat denser than usual. There are no regenerating nerve fibres and the bundles are filled with necrotic material. The nerve fibres grew down for only 12 mm into the proximal end of the graft.

FIGURE 6 - Low-power view (cross-section) of a normal human peripheral nerve to demonstrate general histological features. Nerve fibres with their individual myelin sheaths form small groups which are united into four or five larger and three smaller nerve bundles. Inside the nerve bundles, as well as among them, there is connective tissue which binds the whole complex structure into a large, well-knit cord.

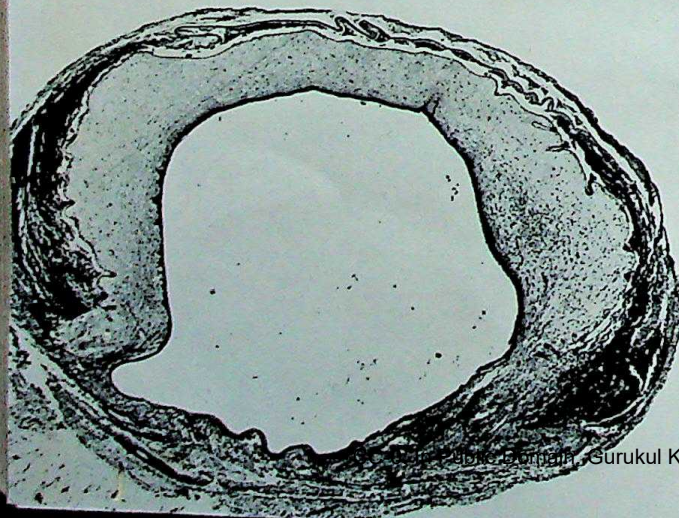
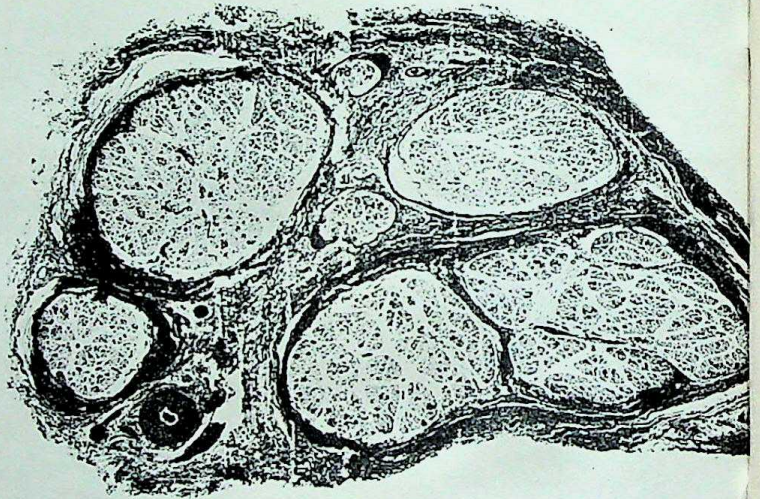


FIGURE 7 - Low-power view of a corneal homograft from a guinea-pig. In order to avoid mechanical injury to the cornea the whole anterior part of the eye, including some of the sclera, the iris, and part of the ciliary processes, was inserted subcutaneously in the host. When removed twenty-one days after insertion for histological examination, it could be dissected away from the host tissues without any serious difficulty. Owing to the pressure of surrounding tissues and because of the shrinkage of the non-corneal elements of the graft, the cornea became turned inside out and converted into a small cyst. Apart from these changes, there is little alteration in the histological features of the graft. Its epithelial covering is retained, and the ground-substance gives the characteristic metachromatic staining after the application of certain specific dyes.

more violent and speedier host reaction. It is interesting to note that recent work suggests that plants also may form antibodies in response to antigenic stimulation. Some intergeneric plant grafts grow for four or five weeks, then the scion stops growing and dies. Attempts to grow new scions of the same species on the same stock all fail. Another interesting example of antibody formation by serum is the production of nephrotoxic ('Masugi') nephritis. Extracts of rats' kidneys are injected into ducks, and the serum from the treated ducks is later injected into other rats. These animals develop an inflammatory condition of the kidneys, caused by the antibodies formed in the duck serum.

As the host reaction against the graft is due to formation of antibodies in the blood-serum, it was natural to test the fate of homografts where host and donor were of the same blood-group. The results were disappointing. This perhaps is not surprising, for blood-grouping has already extended far beyond the four main groups, and it is possible that blood, in the future, will be shown to be as individually specific as finger-prints.

When a nerve has been cut, the new nerve fibres grow out from the central end, but become lost unless they are guided to their destination along the peripheral end in which the nerve fibres have degenerated and disappeared. For functional recovery it is therefore necessary that the two ends should be reunited either directly or, if there is too large a gap, indirectly by means of a nerve graft. The nerve fibres of the graft have, of course, degenerated. They themselves are not required, but a bridge of living tissue is needed to allow the new nerve fibres from the central stump to cross to the peripheral end. The nerve graft forms tubes along which the new nerve fibres travel. Naturally, nerve autografts cannot be acquired with the same facility and impunity as skin and bone homografts.

After the 1914-18 war, and again during the recent war, intensive research was carried out by all the combatant countries to find some method of treating nerve homografts so that they would survive and could be used to bridge large gaps in injured nerves. Again the results have been disappointing (figures 3-6), and in Britain the nerve homograft is at present regarded as a failure. This attitude, however, is not accepted in America or Russia. Indeed, in America 'nerve banks' have been established, but so far there are no reliable records of functional recovery after the use of nerve homografts in man, although an occasional promising result has been obtained in animals.

The history of the mammalian homograft, experimental and clinical, is very largely one of disappointment, but there are two exceptions: cartilage and cornea (figures 2 and 7). Homografts of cartilage have been used successfully to build up the bridge of the nose. Examined three and a half years after the operation, the grafts had the normal histological structure of living cartilage.

The first record of the clinical use of corneal grafts (which must, of course, be homografts) is as far back as 1878. Where blindness is due to corneal opacities, sight can be restored by a transplant operation. Are there related qualities in cartilage and cornea which account for their ability to survive as homografts? All these tissues are avascular. The intercellular or ground substances of cartilage and cornea contain mucoproteins, the prosthetic groups of which are chemical isomers, and all give a characteristic metachromatic staining with certain dyes. The nutrition of these avascular tissues is probably maintained by the breakdown of the polysaccharide components of the mucoproteins by enzymatic action. Of greater significance is the fact that these mucoproteins are non-antigenic and inhibit the formation of antibodies. Recent experimental and clinical work has demonstrated the protective nature of the mucoproteins and their influence on host reaction to living foreign elements. There seems little doubt that they furnish the common denominator which endows cartilage and cornea with their unique ability to survive as homografts. These are, however, but isolated exceptions.

Each individual appears to evolve a specific biochemical background within which the organs and tissues work together though preserving their own characteristics. The autograft is attuned to the biochemical system of the organism, and is therefore accepted as a transplant, but the homograft is an alien—it excites antagonism and is thereafter destroyed. Future research on the homograft will probably proceed in two directions: (1) further investigation of methods of treatment of the homograft before implantation, with the object of making it non-antigenic or conferring protection against the host reaction, and (2) the serological approach to the problem. As the number of known blood-groups steadily increases, it might seem that the prospects of successful homografting would recede, but with a further knowledge of serological reactions it may be possible to devise a form of negative vaccination which will prevent rather than promote antibody formation.

Gravity surveys in submarines

F. A. VENING MEINESZ

Although the astronomical-geodetic method for determining the figure of the Earth is satisfactory on land it fails at sea. The use of the multiple-pendulum method devised by Professor Vening Meinesz enables gravity determinations to be made at sea, but it is necessary to mount the apparatus in a submarine in order to avoid the waves. The numerous surveys made by the author, and by others who adopted his method, have given us considerable knowledge of the Earth's configuration at sea and of variations in its density there.

Gravity observations on the surface of the Earth are made for two purposes, viz. for determining the figure of the Earth and for getting information about the distribution of densities in the Earth. The first possibility was recognized in broad outline by Newton and Huygens in the seventeenth century, and since then the theory has been further developed. In the eighteenth century Clairaut derived a formula for the relation between the flattening and the gravity of a spheroid of revolution, and in the middle of the last century Stokes in his theorem gave a complete solution for the detailed figure of the geoid expressed in the gravity anomalies on the Earth's surface.

We see that gravity determinations can thus provide us with another way of obtaining the figure of the Earth besides the method of measurements of arc or, more precisely, the astronomical-geodetical method which up to recently was the more usual way of pursuing this object. This led the geodetic services of many countries to take up gravity research, and in the last few decades the material has been quickly increasing; nowadays the number of stations where gravity has been determined far exceeds 10,000.

The gravity method has one great advantage over the astronomical-geodetical one, viz. the possibility of finding the figure of the Earth also in ocean regions which, as is well known, constitute 70 per cent. of the Earth's surface; it is clear that the other method must fail there. The necessary condition is that gravity should be determinable at sea with a reasonable accuracy. So far, only one method has provided this accuracy: a special pendulum method which, by using more than one pendulum, allows us to eliminate the main part of the disturbance caused by the ship's movements while the other smaller parts can be measured and computed. Elaborated by the writer of this paper in 1923, the method has since received a valuable contribution from B. C. Browne of

Trinity College, Cambridge, who indicated two further small disturbance terms which, formerly neglected, have since been taken into account.

In general the method is difficult to apply on board a surface vessel; the ship's movements are usually too great. It is possible to obtain greater stability by making the observations in a submerged submarine which can dive below the disturbed surface layers of the water. At a depth of some 30 metres we find already a great reduction of the ship's movements. A long swell is still perceptible at that depth, but the accelerations given by these slow waves are small enough to allow the above-mentioned method to be applied. In general, an accuracy of one part in two hundred thousand can thus be obtained, and this is sufficient for most purposes. Occasionally it is necessary to dive more deeply.

In the course of time the second purpose for making gravity observations has more and more come into the foreground, viz. the investigation of densities in the Earth. For the geologists it started with detailed research by oil and mining companies for prospecting purposes in the upper few kilometres of the Earth's crust. The principle is simple; it is clear that excesses and deficiencies of density below the observer must be revealed by corresponding deviations of the attraction, i.e. by positive and negative gravity anomalies at the surface. It is not possible to derive exactly the location of the density-deviations from the surface anomalies, but in many cases a satisfactory estimate can be made.

At the same time, some of the geodesists engaged in gravity research for geodetic purposes on a larger scale studied the significance of the fields of anomalies they found. Gradually, an interpretation of these anomalies as due to larger mass-deviations, mostly at greater depth than the above-mentioned, was suggested. The principle of isostasy, discovered in the middle of the

nineteenth century through astronomical observations in India, was investigated by many geodesists in the light of the gravity results. This principle supposes the compensation of topographic masses by masses of opposite sign at greater depth, i.e. deficiencies of mass below a mountain-range, and mass-excesses below a lack of mass at the surface. Nowadays the explanation of this phenomenon suggested in 1855 by Airy (then Astronomer Royal) is widely accepted; he ascribed it to hydrostatic equilibrium of the crust on the plastic substratum. More recent studies by Hayford, Bowie, Heiskanen, and many others have given us further insight into this phenomenon; it now seems probable that the thickness of the rigid crust is in most areas of the order of 30 km. In some cases the equilibrium of the crust is more or less locally realized, but in general this is not so; the crust then reacts more or less as a whole to the tendency towards floating equilibrium.

Besides the isostatic compensation-masses, gravity reveals the existence of other mass-deviations from the regular distribution. In some cases it even seems probable that these deviations from the normal density occur not in the crust but in the deeper plastic layers, and this might well point to currents flowing there, because the presence of these masses implies deviations from the normal equilibrium. It is hardly necessary to stress the importance of such conclusions. If subcrustal currents do indeed occur in the Earth, we may arrive at an explanation of the forces bringing about the lateral compression of the crust leading to folded mountain ranges, which up to now have not been satisfactorily explained in any other way. The high viscosity of these subcrustal layers must bring about a powerful drag exerted by the currents on the crust. Perhaps we may thus also explain the intermediate and deep earthquake-foci which occur at depths of 100-700 km, i.e. far below the rigid crust; it is not unlikely that the currents reach down to these depths.

In the last quarter of a century the two groups of gravity investigators, the geodesists and the geologists, have gradually met on the common ground of geophysics, and the interests as well as the surveys have merged into a whole, opening a hopeful vista for future research. In geodesy the opinion is gradually forming that by organizing the gravity surveys in such a way that light is shed on the great geophysical problems of crustal phenomena and possible subcrustal currents, more insight will be obtained into the distribution in general of gravity anomalies over the Earth's

surface, and that thus the main problem of geodesy, the determination of the figure of the Earth, will be brought nearer to solution.

It is clear after this short introduction on gravity observations that, in the new orientation of this work, research at sea must be of primary importance. Many of the main problems about the Earth's crust lie in the oceans. As two of the most important ones we may mention the problem of the character and origin of oceans in relation to those of continents, and in the second place the research on island-arc areas which play such a predominant part in the great tectonic evolutions of the Earth's crust.

Since the writer started his research at sea in 1923 he has had many opportunities of doing extensive work; he has made ten expeditions with submarines of the Netherlands Navy and two with U.S. submarines, covering together more than 130,000 sea-miles and making about 900 dives.

The first and third voyages in 1923 and 1926-7 were mainly aimed at the geodetic problems. On the first trip, the Dutch submarine Hr.Ms.K.2 went via Suez towards Java, and on the third, Hr.Ms.K.13 went via Panama towards the same destination; together they encircled the globe. The principal purpose of the two expeditions was to get data about the hypothesis, often defended by geodesists, that the figure of the Earth is approximately a three-axial ellipsoid or, in other words, that the equator too shows a slight flattening. The results did not support this hypothesis. Although it was found that gravity shows widespread fields of anomalies, their distribution does not agree with a regular flattening in the equator-plane. They seem rather to be connected with extensive processes in the upper thousand kilometres of the Earth, perhaps in even a much shallower layer. For a more decisive answer to this question, however, additional encircling series of observations at other latitudes will be required.

The opportunities of obtaining data have already been used for various geographical problems. Observations were, for example, made near volcanic islands, as Fayal (Azores), the Canary Islands, and Oahu (Hawaii Archipelago); over deep troughs such as the Brownson Trough north of Porto Rico, the Guam Trough, the Yap Trough, and the Mindanao Trough; in profiles at right angles to coasts, e.g. four profiles on the west coast of America between Panama and San Francisco; and in profiles over island-arcs in the West and East Indies. After arrival in Java a special research was made of the Java Trough, to

the south of this island, which was crossed in four detailed profiles.

The cruise of Hr.Ms.K.13 via Panama to Java took us about seven months, and we had uninterrupted crossings of three weeks. This meant a great strain for everybody on board, especially owing to the great number of dives required for the gravity research. Each dive took us about an hour. When at a certain depth stability had been re-established, the pendulum-apparatus was unclamped, the recording camera was put in order, and the pendulums were started. Thermometer, barometer, and hygrometer readings completed the observations. After 30-40 minutes the observation was finished and the pendulums were stopped and clamped. The normal emptying of the tanks then brought the ship again to the surface and the trip was resumed.

To obtain the necessary accuracy, the rate of the time-recorders on board had to be determined with an accuracy of 0.02 second per day, so as many accurate radio time-signals as possible were taken. As long as chronometers were used this accuracy was hard to obtain, but for the last expeditions crystal-controlled clocks were taken, and afforded a great improvement.

For two reasons it was important to make as many soundings as possible during the trips. In the first place we need the submarine topography in order to be able to derive its gravity effect and so to correct the result for it. Secondly, the topography in itself may give important geophysical indications which may be of help for interpreting the gravity anomalies. During the first voyages echo-sounding was possible only during submer-sion, but for the later trips steps were taken to obtain a continuous depth-profile over the whole route.

For gravity research more stress has to be laid on accurately determining positions of the ship than in normal navigation. They are also required for deriving the east-west component of the current which, as Eötvös noted at the beginning of this century, is needed for correcting the gravity result. The point is that gravity is a combination of the attraction by the masses of the Earth and a smaller effect due to the Earth's rotation; this last effect is disturbed by an east-west speed of the ship which increases or diminishes the speed at which the observer rotates around the Earth's axis.

The results obtained in the East Indies had shown remarkable gravity anomalies, and it seemed promising to pursue the research in these

island-arc areas in order to get a deeper insight into the phenomena of the Earth's crust there. In 1928 the U.S. Navy, through the medium of the Carnegie Institution of Washington, generously offered a submarine trip to the West Indies and this expedition gave important further information. The writer was accompanied on this voyage by Dr Fred E. Wright and Mr Elmer B. Collins. It was found that the large deficiency of gravity over the Brownson Trough continues in a belt to the west, i.e. north of Haiti, where no trough is present.

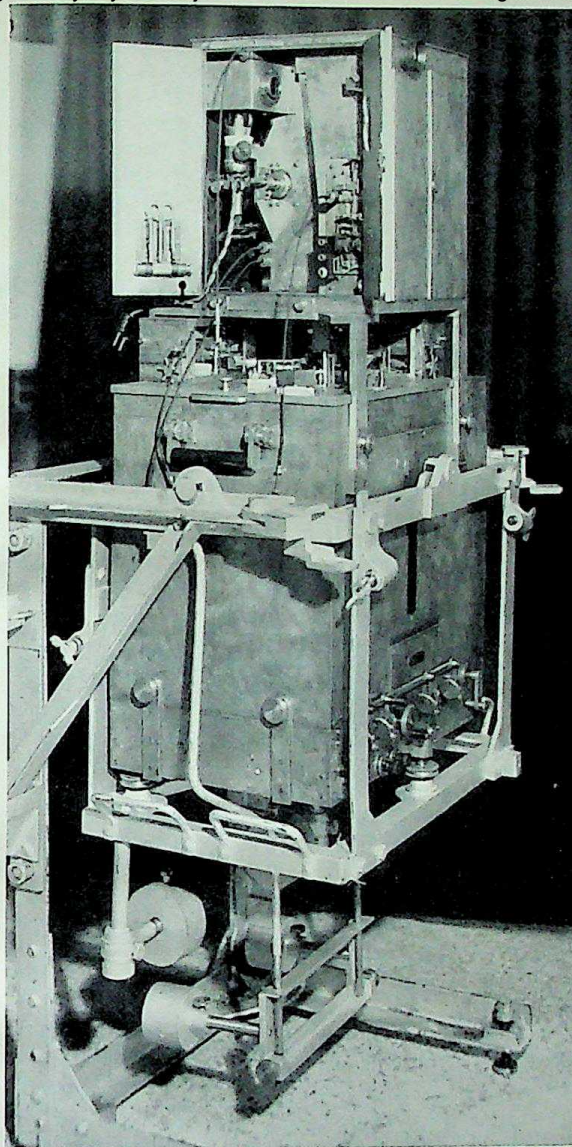
In 1929 and 1930 the author was enabled by the Netherlands Navy to make three extensive cruises through the Indonesian Archipelago, and the new data, with those previously gained, gave him a network of more than 300 gravity values covering the whole archipelago. It shows remarkable features. The most outstanding is a narrow belt of large deficiency of gravity running through the whole archipelago and obviously coinciding with the belt of strongest recent tectonic activity formed by the outer island-arc. Although this belt is clearly connected with the deep troughs in the area it does not coincide with them; its axis is in general just beside the troughs. The belt, moreover, continues in the areas devoid of troughs.

This result was in good agreement with what was found near Haiti, and there was thus every reason to suspect a similar feature over the whole island-arc area of the West Indies. Further information about the West Indies was given by two more gravity expeditions of the U.S. Navy in this area, one on board the U.S. submarine S 48 in 1932 which the writer had the privilege to make in company with Dr Harry Hess of Princeton and Mr T. T. Brown—it was organized by Professor Richard Field of the same University—and one on board the U.S. submarine *Barracuda* in 1936, led by Dr Maurice Ewing, Dr Harry Hess, and Lieut. Hoskinson of the C. & G.S., during which Ewing first introduced the improvement of a crystal-controlled timekeeper instead of a chronometer. The latter voyage especially showed our surmise to be well founded. Here too an outer-arc is present, though partly submerged, over the islands of Barbados, Tobago, and Trinidad, which also reveals a belt of strong negative anomalies; the part found north of Haiti and Porto Rico belongs to it.

We cannot here discuss fully the meaning of these remarkable belts of strong negative gravity anomalies, which have also been found near Japan and the Bonin Islands and near Calabria,

but a short mention may be made of an interpretation which at present seems most likely. It appears probable that the great lateral compression of the crust in these belts, which is indicated by the folding and overthrusting of the surface-layers found on the islands in the belts, causes as its main effect a downward buckling of the crust. The large crustal bulge thus formed at the lower boundary of the crust replaces the denser substratum and causes the great mass-deficiency which brings about the negative gravity anomalies. This hypothesis explains also that the first stage of the tectonic belts is the development of a geosyncline which can be interpreted as the downward crustal wave leading at a later stage to the down-bulging mentioned. The surface-layers of the crust are partially squeezed out during the latter process and form the folded layers found by the geologists in these belts.

Besides the expeditions already mentioned in this paper the writer made the following trips: an expedition in 1932 on board Hr.Ms.O.13 in the North Atlantic to investigate the area around the Azores and Madeira and between those islands and the coast of Europe; an expedition of eight months in 1934-5 on board Hr.Ms.K.18 via Buenos Aires, Cape Town, and West Australia to Java; an expedition in 1937 on board Hr.Ms.O.16 to Washington and back again; and a return voyage on board Hr.Ms.O.13 from Curaçao (West Indies) to Holland. The French Navy made two gravity expeditions in the western



Complete pendulum apparatus for submarine gravity determination, showing the recording camera on top. The whole is mounted in gimbals.

Mediterranean led by Commander Marti of the Hydrographic Survey, viz. in 1933 with the submarine *Fresnel* and in 1936 with the submarine *Espoir*, and the Italian Navy twice put a submarine at the disposition of Professor Cassinis for research in the Mediterranean areas. Observations were also made on board Japanese submarines in the neighbourhood of Japan, and in U.S.S.R. submarines in the Black Sea and elsewhere. The British Navy took an active part in gravity research by organizing a submarine expedition in the Atlantic in 1939 led by E. C. Bullard and B. C. Browne, which, however, was called back shortly after the start because of the political tension, but a new expedition took place under the leadership of Browne, Nieuwenkamp, and Cooper in the summer of 1946; it investigated the waters to the south-west and west of England. A further expedition was made in 1948 by Browne.

During these different expeditions a great number of gravity values have been obtained, and many data have been found near the continental margins which shed light on the problem mentioned above of the relationship of continents and oceans. In general, they have confirmed the results obtained by seismology, which point to the continents being blocks of lighter matter floating on the deeper layers, and this floating lighter layer being much thinner beneath the oceans. Gravity measurements indicate nearly everywhere a sudden thinning of these layers near the continental border.

SULPHONAMIDE DRUGS

The Sulfonamides and Allied Compounds, by *Elmore H. Northey*. Pp. xxvii + 660. Reinhold Publishing Corporation, New York. 1948. 75s. net.

Since the discovery of the chemotherapeutic action of sulphonamide drugs in 1932 over 5,000 compounds of the type have been synthesized and examined both pharmacologically and for chemotherapeutic activity. Since much of this work has been unpublished or is not easily available, chemists and biologists alike will welcome this extremely valuable attempt by the Administrative Director of the Stamford Research Laboratories, American Cyanamid Company, to assemble and co-ordinate both published data and those supplied directly by his own and other American firms. The system of nomenclature developed by the author and his associates enables him to group the compounds in a logical fashion, so that both text and reference tables are easily consulted even by those not primarily chemists. Methods of synthesis and chemical and biological properties are given for the more important members of each group, together with available references, and the monograph is a standard reference book for all working in this field.

The final chapters, which contain contributions by two biologists of the staff of the American Cyanamid Company, cover such topics as the pharmacology, mode of action, and clinical evaluation of sulphonamides, and form an adequate and critical survey of present knowledge. Dr Northey is to be congratulated on having brought together into a coherent and readable form so many diverse studies, and his monograph should not only stimulate interest in the wider and more intelligent use of existing drugs, but should be of material assistance in the development of other and equally important chemotherapeutic agents.

E. S. DUTHIE

PRINCIPLES OF RADAR

Principles of Radar, by *Denis Taylor and C. H. Westcott*. Pp. 137. University Press, Cambridge. 1948. 12s. 6d. net.

The importance of radar in the recent war is now widely known; its uses in peacetime are becoming rapidly more numerous. In the circumstances, the publication of this excellent short introduction to the basic principles

underlying the design of complete radar systems is very welcome. Further books in the same series, which is edited by Mr J. A. Ratcliffe, will deal in detail with the many new techniques involved. The authors of this book write from first-hand experience, having been directly responsible for the development of many radar systems for the Royal Air Force during the war.

They consider first the generation and detection of the radio signals by which targets are located, then the physical conditions governing the strength of echo returned, the measurement of range and bearing, and finally the design of typical radar systems for particular purposes.

The style is clear and readable, and the presentation should appeal to physicists, and to engineers with some knowledge of physics. An elementary acquaintance with normal radio practice is assumed. In some places the discussion is not very detailed, and although this generally represents a gain in clarity, more references to further sources of information would have been useful. Nevertheless the book contains much more than its size might suggest, and for the topics discussed will undoubtedly be preferred to many larger works.

J. M. M. PINKERTON

CONCEPTIONS OF PHYSICAL PHENOMENA

L'évolution de la Notion du Phénomène Physique des Primitifs à Bohr et Louis de Broglie: Leçons sur l'histoire de la pensée scientifique professées à l'Université de Bruxelles, by *Jean Pelseuer*. Pp. 177. Office internationale de Librairie and Office des Cours du Cercle des Sciences, Brussels. 1947. n. p.

This little book is an attempt to provide the student with a summary of the conceptions of the physical basis of the universe by tracing them from primitive thought to their most modern presentations. Dr Pelseuer is specially concerned with the continuous process by which observational activity has modified cosmological beliefs, the changes in which have, in their turn, transformed metaphysical conceptions. An interesting parallel is drawn by him between the impact of Newtonian on Cartesian physics in the seventeenth century, and that of the 'new' physics on the classical system in the twentieth. He makes a good case for the view that

'scientific controversies of every period arise far more from differences of temperament than from knowledge or ignorance of facts.' A glimpse is given of successive theoretical concepts—mechanist, energy, irreversibility, entropy, atom, wave, and quantum theory, and the latest hypotheses as to the relation of statistical truth to the principle of indeterminism. After his final quotations from Bohr, Jeans, and de Broglie on these themes, Dr Pelseuer asks 'May not the quantum theory, together with the fall of mechanist theory which it has seemed to consecrate, nevertheless present us with another crisis in physics such as was produced by the doctrine of energy?'

Dr Pelseuer's student-readers cannot fail to become aware of the extreme complexity of the problems involved, and may thus be protected against catchwords based on facile generalizations and gain some hint of the supreme joy of scientific exploration in spite of, or perhaps because of, the lack of finality that is inherent in scientific achievement.

CHARLES SINGER

CHEMICAL DICTIONARY

Dizionario di Chimica, Vol. I (A-C), by *Michele Giua*. Pp. 1073 with 28 plates and 451 figures. Unione Tipografico-Editrice Torinese, Turin. Second Edition, revised and enlarged. 1948. 7,000 lire.

The second edition of Professor Giua's great dictionary brings both the subject matter and the bibliography up to 1942 and, in some cases, to 1946, and several sections, particularly among those dealing with biochemistry, have been completely rewritten. The work is intended for general use, and deals with theoretical, practical, and industrial aspects. A historical sketch introduces each of the more important substances; physical and chemical properties are stated, and methods of preparation, on both laboratory and industrial scales, are described. Short biographies of the world's great chemists are given.

Alphabetical arrangement of complex and interrelated concepts presents the difficult problem of choosing those that should rank as main entries and those that are best treated as subsidiary under some main heading. The solution here adopted should meet the requirements of the general reader. To take an example, general properties of

acids, acidity, dissociation, are found under *Acidi*, with subdivisions inorganic and organic, the latter comprising carboxylic acids only. The inorganic acids are separately treated under *Acido cloridrico*, *Acido solforico*, etc. Special classes of non-carboxylic organic acids are entered separately, as *Amino-acidi*, *Acidi acetilencarbonici*, etc. Separate entries are found for the numerous organic acids outside the above classes, and these entries comprise the salts and derivatives of the acids. A clear definition is given for each group, and cross-references guide the careful reader. The whole section on acids, which fills over a quarter of the volume, is a measure of the untiring labour and profound knowledge behind this impressive volume. The completion of the work in the tragic circumstances of the years 1943-6 bears witness to the burning faith and the indomitable optimism to which Professor Giua gives such touching expression in his preface.

PLASTIC DESIGNING

Applied Plastic Product Design, by Robert L. Davis and Ronald D. Beck. Pp. vii + 285 with many illustrations. Chapman and Hall Limited, London. 1947. 28s. net.

In this book the authors survey the considerations of design governing the use of plastics as materials in their own right and not as mere substitutes for wood, metal, glass, etc. The work is mainly intended for young newcomers to the plastics industry, and for busy specialists in other fields who wish to learn something of the possibilities and limitations of the use of plastics. After a worthless and inaccurate introductory chapter on the history, development, properties, types, and methods of manufacture of plastics, which merely irritates the reader, successive chapters deal with the design of moulds and moulded components, together with problems arising from the moulding of undercuts, threads, inserts, etc. The design of extrusion parts, of high and low pressure laminated parts, and of parts fabricated from sheets, rods, and tubes is then considered, and the book ends with remarks on the economics of moulding and the general properties of moulded plastics. A glossary of technical terms, again marred by inaccuracies, is included.

In spite of its faults, the book should give many useful hints to the young man intending to enter the plastics

industry. The experienced designer, or the busy specialist in other fields, will gain little from it. J. M. WALTER

HISTORY OF CHEMISTRY

Chymia—Annual Studies in the History of Chemistry. Tenney L. Davis, editor-in-chief. Volume 1. Pp. xiv + 190, with 20 plates. University of Pennsylvania Press, Philadelphia. 1948. \$3.50 net.

All those interested in the history of science in general, and of chemistry in particular, will welcome the appearance of the first volume of this series which is being issued under the aegis of the Edgar F. Smith Memorial Collection. The editorial board consists of the leading American scholars in the field and the consulting editors represent the foremost experts from other countries. These facts should guarantee the quality of the articles, and the first volume sets a high level of interest and scholarship as well as presenting a remarkable and praiseworthy catholicity of subject matter. The subjects dealt with in the present volume are: Frederick Accum (1769-1838); Dr C. A. Browne (ob. 1947); The Argument of Morien and Merlin (an early English alchemical poem); Thomas Thomson (1773-1852); *L'Ecole des Chimistes Français* vers 1840; Factors which led Mendelev to the Periodic Law; The early use of potassium chlorate in pyrotechny; The early chemical and pharmaceutical history of calomel; The concepts of substance and chemical element; Priestley settles the water controversy; Scottish alchemy in the 17th century; Carl Weltzein and the congress at Karlsruhe; and Pierre Dulong's life and work (1785-1838). The book is pleasantly printed on good quality paper, and the only slight criticism that could be made refers to the plates, which are not reproduced quite as clearly as might be wished.

DENIS DUVEEN

ATOMS AND NUCLEI

The Atom and its Energy, by E. N. da C. Andrade. Pp. xi + 196, with 12 plates and 17 diagrams. G. Bell and Sons Limited, London. 1947. 10s. net.

Many popular-science writers tend to assume that the layman has necessarily the mentality of a schoolboy and must be addressed in words of one syllable. Professor Andrade evidently writes for the numerous class of readers who are quite literate and not intimidated by

long words though unfamiliar with the elements of science. As expected of any book by Andrade, who uses words like scientific instruments and who knows the great writings of the past as intimately as he knows atoms, this volume makes attractive reading. Of eight chapters, only the last one deals with atomic energy, the others tell the story of the atom in the scientist's, not the newspaper, sense. The presentation is mostly descriptive, using only a few diagrams; this again is probably as it should be for the mature reader who has little scientific training. Technical detail must, of course, be omitted, but the essence of the subject is always there, and the grounds on which the reader is to accept a statement are (with simplification) those which convince the expert.

Frequent analogies help, though one or two (such as the comparison of positive and negative electrons with good and evil on page 44) are not too happily chosen. I suspect they are not really meant to help but belong to those little asides characteristic of Andrade such as the remark about hydrogen peroxide 'by which blondes are manufactured.' While the book does not scorn long words, it does take trouble with technical terms; the warning given with the terms 'proton' and 'photon', that each must not be confused with the other, is a wise precaution. I doubt, however, if quicksilver is really more familiar to anybody than mercury—here Andrade's love for the classics shows up.

Each chapter is headed by singularly apt quotations from great physicists or others. Another nice touch is a photograph of a painting by Lucas van Leyden remarkably similar to an atom-bomb raid. For a book written for the classically educated layman, an uneducated scientist is hardly a typical reader; yet this reviewer greatly enjoyed it and believes that it will appeal to the readers for whom it is meant.

R. E. PEIERLS

CLOCKS AND WATCHES

Horology, by J. Eric Haswell. Pp. xvi + 288 with 111 figures. Chapman and Hall, London. 1947. 16s. net.

The sub-title of this book is 'The Science of Time Measurement and the Construction of Clocks, Watches, and Chronometers.' On the practical constructional side the book can be highly commended; the diagrams of escapements and other mechanisms are excellent and of particular value to

Digitized by Arya Samaj Foundation Chennai and eGangotri

the practical watchmaker. The section on time measurement, on the other hand, is poor and inadequate. The work was first published in 1928, when the Shortt free-pendulum clock, which set a new standard of accuracy, was in its infancy. It was reprinted in 1937, with a supplement which amplified certain sections and corrected various erroneous statements. The present edition is merely a reprint of the 1937 edition, with its supplement. It is regrettable that the opportunity was not taken of bringing the work up to date, for there have been some notable advances in horology in the last two decades.

The Shortt free-pendulum clock is inadequately described in the chapter on pendulums, and the essential point that the slave clock must be adjusted to have a natural losing rate of about six seconds a day is not mentioned; the principle of the 'hit and miss' synchronizer is consequently not explained. Though there is a chapter on electrical clocks, no mention is made of synchronous clocks. Nor is there any reference to the quartz crystal clock, which has set the highest standard of accuracy in horology, and which is capable of detecting changes in the rate of rotation of the earth. It is unsatisfactory still to find the statement (on p. 1) that 'the earth itself is a perfect clock.'

The book has therefore distinct limitations. Within these limitations, and more particularly in the descriptions of clock, watch and chronometer movements, and of striking, chiming, calendar, and repeating mechanisms, it is of great value. Should a further edition be required, it is to be hoped that the author will thoroughly revise the book and bring it up to date, so that it will give a more satisfactory picture of modern horology. It will then be possible also to include an account of the recently invented magnetic escapement, which is probably the most important development in pendulum clocks for domestic use since the invention of the dead-beat escapement.

H. SPENCER JONES

ELECTROCHEMISTRY

An Introduction to Electrochemistry, by S. Glasstone. Pp. vi + 557. Van Nostrand Co., New York. 1942, reprinted 1946. 31s. 6d.

In this work the author has endeavoured

to provide a concise survey of the existing knowledge of electrochemistry including its theories and concepts. He has been ruthless in excluding the older material and theories and has aimed at giving the reader 'the modern point of view in electrochemistry.' No attempt has been made to trace the development of the modern interpretations, and in this respect the student has been deprived of a most valuable aspect of the subject, for he can gain no clue from the text as to why certain theories, still held by many living electrochemists, should be superseded. The treatment is too rigid and assumes that a substantial degree of finality has been reached, despite the fact that electrochemistry is a subject undergoing rapid development. Very often the experimental descriptions are too cursory and important points are omitted. Thus in the description of the moving boundary method of measuring the transport numbers of ions there is no indication of how the 'moving boundary' in a colourless solution can be detected.

The aim of the book is 'to serve as an introductory text for those who intend to specialize in electrochemistry' and it claims to be suited to the needs of students of physical chemistry and to those of chemists, physicists, and physiologists whose work brings them in contact with a variety of electrochemical problems.' Although the present volume is much longer than Professor Glasstone's first book *The Electrochemistry of Solutions*, he regards that work as being 'primarily a work of reference.' In the opinion of the reviewer the first book meets the needs of chemists and non-chemists much more satisfactorily than does the new volume. The chief reason for this is that, unless the student is well versed in modern thermodynamics, particularly in regard to the concepts of chemical potential and activity, much of the text of the new volume must inevitably remain obscure.

Provided that a student is not lacking in thermodynamics and is prepared to accept the author's views on what constitutes modern physical chemistry and to tolerate the rather didactic treatment, he might find the book of assistance. To the reviewer it appears that Professor Glasstone's treatment of electrochemistry in his *Text Book of Physical Chemistry* is not only adequate

but much more intelligible to a student requiring an introductory treatise.

H. T. S. BRITTO

ORGANIC SYNTHESSES

Organic Syntheses (Volume 27), edited by R. L. Shriner. Pp. 121. John Wiley and Sons, Inc., New York. 1947. 13s. 6d.

This volume maintains the high tradition of those which have preceded it, and the series has rightly earned for itself an honoured place among standard reference books in all chemical laboratories and libraries. The fully detailed descriptions of the preparative methods have in all cases been thoroughly checked, and make these volumes of great value to the non-organic chemist who often finds difficulty in repeating preparations described briefly in original papers in the scientific journals. The fact that the method is detailed in *Organic Syntheses* is a guarantee that the compound is really available in the yield stated, and the preparation may confidently be left in the hands of any competent laboratory worker.

Among the thirty-seven preparations described in the volume under review are the following which are likely to be of general interest: β -alanine, from acrylonitrile via β -aminopropionitrile; benzalacetone dibromide; allyl; *tert*-butylamine from 2-amino-2-methyl-1-propanol; decamethylenediamine by reduction of octamethylene dicyanide; N-diethylaminoacetone; dihydroresorcinol by reduction of resorcinol; ethyl α -isopropylacetoacetate; 4-ethylpyridine from pyridine and acetic anhydride via 1:4-diacetyl-1:4-dihydropyridine; glycolonitrile; 8-hydroxyvaleraldehyde from 2:3-dihydropyran; 6-methoxy-8-nitroquinoline from 3-nitro-4-aminoanisole; $\alpha\beta$ -dibromo- β -formylacrylic acid from furoic acid; *m*-nitrodimethylaniline; 3-penten-2-ol; rhodanine; stearic acid; tetraiodophthalic anhydride by iodination of phthalic anhydride in presence of fuming sulphuric acid; *m*-thiocresol; *o*-toluic acid from *o*-xylene by oxidation with nitric acid; *p*-toluic acid by oxidation of *p*-cymene; *o*-toluidine-sulphonic acid; and 1:3:5-triacetylbenzene from acetone via acetoacetaldehyde.

The subject index covers the contents of volumes 20-27.

W. BAKER

पुस्तकालय 176

CC-0. Mumukshu Bhawan Varanasi Collection, Haridwar

हस्तिना

stude
sc.
ITTO

, edit
Wil
3s. 6

high
exceede
ned fe
mong
chem
Th
f th
case
mak
e nor
find
ation
ers i
t tha
organi
t the
n the
may
of any

ation
review
ely to
from
nitrile
tert.
nyl-1-
e by
nide;
lrore-
cinol;
ethyl-
acetic
4-di-
5-hy-
dihy-
oline
β-di-
uroic
nten-
etra-
ation
ce of
resol;
ation
by
dine-
etetyl-
alde-

tents
KER

यस पुस्तक वितरित न की जाय
NOT TO BE ISSUED

सन्दर्भ ग्रन्थ
REFERENCE BOOK

